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ABSTRACT

The current energy situation in the United States is a web of complicated and related elements. This document attempts to address some of these variables in presenting interdisciplinary energy lessons taken from instructional packets previously developed by the Project for an Energy-Enriched Curriculum (PEEC). The 19 physical science lessons include background information, teaching suggestions, student handouts and activities. Each lesson also contains the objectives of the lesson, target audience, a suggested time allotment, and sources for more information. Lesson topics include the following: (1) the laws of thermodynamics; (2) nuclear power; (3) energy resources and technologies; (4) biomass conversion processes; (5) synfuels produced from coal; (6) automobile engines; (7) new inventions and improvements; (8) energy quality; (9) appropriate technologies; (10) the greenhouse effect; (11) global temperature changes and possible effects; and (12) the use of water in coal and oil shale production, and in thermoelectric power plants. The activities are intended to be infused into existing courses in chemistry, physics, and geology. (TW)

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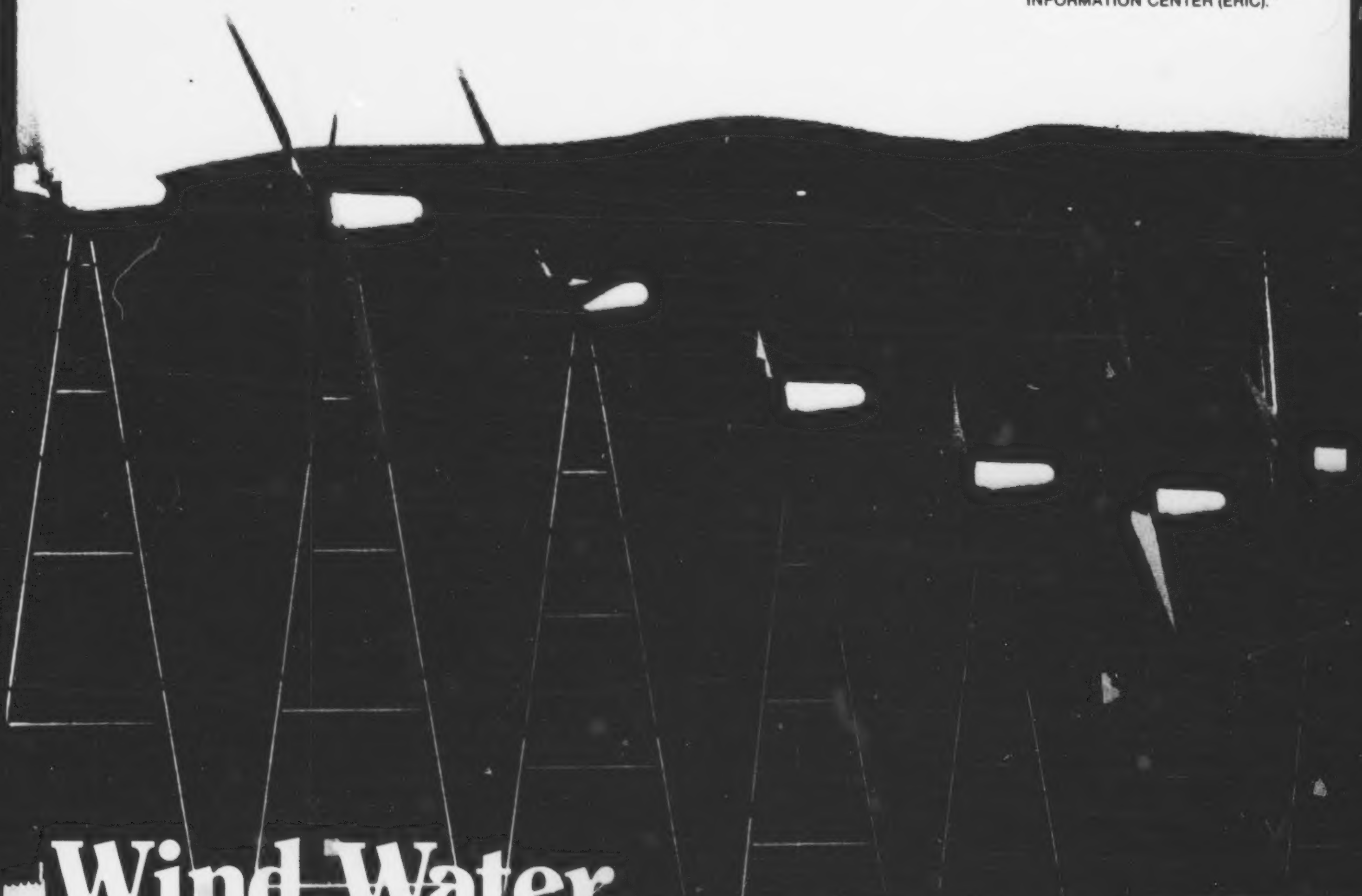

Wind, Water, Fire, and Earth

Energy Lessons for the Physical Sciences

SE 048 143

National Science Teachers Association

Wind, Water, Fire, and Earth

Energy Lessons for the Physical Sciences

A selection of units from the Project for Energy Enriched Curriculum

National Science Teachers Association

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Introduction

The Project for an Energy-Enriched Curriculum (PEEC) was a long-running NSTA effort to infuse energy/environment/economic themes into the K-12 curriculum. PEEC was supported over seven years by more than $1.5 million from the Energy Research and Development Administration and the U.S. Department of Energy. The project took many forms—materials development, implementation and distribution, communications and outreach—but the centerpiece was the series of 40 instructional packets. These packets were interdisciplinary, in recognition of the overflow of energy issues into science, social studies, mathematics, and English; and they were infusable (hence the name "energy-enriched"), meaning that instead of adding to the already impossible curricular demands on teachers, the packets were designed to let teachers teach the requirements—but through energy.

To locate the niches where energy themes could be used to convey traditional lessons, and to bring the perspectives of several disciplines to bear on energy topics, PEEC relied on teachers. Teachers wrote, tested, and reviewed each packet. And teachers—about 1½ million of them—requested copies of the first 15 packets that were published. Despite their obvious popularity, internal policy changes at the Department of Energy stopped the publication of the remaining packets. This volume is a collection of lessons from the heretofore unpublished packets.

In this book you will find lessons for chemistry, physics, and geology; and Earth, physical, and general science classes. The lessons are designed to be easy to infuse into existing units; all include background information, teaching suggestions, student handouts, and activities. Many are suitable for more than one course, and many cover energy issues that are not strictly scientific concerns.

We at NSTA hope that these lessons will enrich your teaching and your students' learning.

Lesson 1

Is There A Crisis?

The background of the energy situation is a web of complicated and closely related elements—supply and demand, sources and uses, production and consumption. When supply does not equal demand, a crisis can result. This lesson begins by examining the gap between energy supply and demand, and then introduces the effect of the doubling time of energy consumption on the lifetimes of various fuels. It notes the methods by which studies on growth are calculated, and identifies present uses of energy. To conclude, students hypothesize the possible match or mismatch between future energy demands and sources.

OBJECTIVES

Students should be able to:

- Use graphs to describe present U.S. energy demand and supply.
- Identify future energy supply problems by analyzing trends shown on a graph.
- Calculate resource lifetimes for some nonrenewable energy sources and interpret the results of these calculations.
- Identify the major end-use sectors and the mix of energy sources each one uses.
- Infer whether predictable energy demands can or cannot be met by possible future energy sources.

TARGET AUDIENCE

Students of Physics and Chemistry

TIME ALLOTMENT

Two class periods

MATERIALS

Student Handout 1-1, "Where Our Energy Comes From"
Student Handout 1-2, "The Kink in Our Quest for the Good Life"
Student Handout 1-3, "Lifetime Resource Calculations"
Student Handout 1-4, "How We Use Our Energy"

BACKGROUND INFORMATION

Two factors determine how long our reserves of fuel will last: how much we have and how fast we use it. The simplest of the lifetime equations is:

$$\text{Lifetime} = \frac{\text{Reserve}}{\text{Constant Rate of Use}}$$

We suggest you use this equation with your students to help them solve the lifetime calculations of Student Handouts 1-2 and 1-3. You may wish to point out very early that the problem with calculating lifetimes is that both the reserves and the rates of use change. Both depend on economics, technology, and politics. In addition, lifetime calculations are made difficult by such questions as: Should we assume a decreasing preference over time for a particular energy source, or should we assume an increasing preference? Should we include only reserves that can be extracted now, or should we also include those reserves that are known to exist? Should we try to guess the extent of undiscovered reserves, and simply assume that the cost of extraction will be economical at some later date? What recovery rate should we use? Students must understand that *the assumptions one starts with will greatly influence the lifetime one calculates for a resource.*

The following tables show resource lifetime estimates for both the United States and the world. The first line shows lifetimes based on the equation above. The second line shows lifetimes assuming an average increasing consumption rate. However, neither of these gives an accurate picture of how long the resources will last because consumption fluctuates. The best one can do is to look at various lifetime calculations, along with the assumptions on which they are based, and then draw a conclusion about a resource lifetime.

TEACHING STRATEGIES

Distribute Student Handout 1-1. Have students analyze the circle graphs, paying attention to supply and demand patterns revealed by comparison. Point out the principal energy sources of the United States. Then discuss how much of our proven reserves each of these sources represents. The discrepancy between the reserves of oil and coal and the amount consumed should emerge in this discussion. Have students complete Handout 1-1, and compare their answers in a short discussion.

Answers to Student Handout 1-1

1. Oil; 2 percent.
2. 19 percent; 93 percent.
3. 26 percent; 2 percent.
4. Nuclear and hydro; 3 percent; because hydro is a renewable resource.
5. Students will probably mention that the U.S. is most dependent on oil. We obtain only 20 percent of our energy from coal, although coal constitutes 93 percent of our nonrenewable resources. It seems sensible to consider changing our consumption patterns to match our resource base more closely.

Distribute Student Handout 1-2, "The Kink in Our Quest for the Good Life." Students should decide on the basis of their calculations whether energy consumption can grow for another hundred years at the rate it has grown over the last 130 years. They should understand how demand, conservation, economics, exploration, politics, and reserves are interrelated, and how any one of these factors can affect estimates of resource lifetimes.

Answers to Student Handout 1-2

1. 1875, wood. 1910, coal. 1960, oil and natural gas.
2. Imports.
3. It is a "J" curve, or a growth curve. It can also be called an increasing demand curve, a power curve, or an exponential growth curve.
4. 40–45 years.

5. 35–40 years.
6. About 20 years.
7. (40 + 35 + 20) ÷ 3 = 31.66 or 32 years.
8. 2.2 percent.
9. 100 ÷ 32 ≅ 3
   80 × 2 = 160 × 2 = 320 × 2 = 640
10. Answers will vary. Students should begin to see that unchecked consumption of our conventional sources of energy is not possible considering the amount of those resources.

Distribute Student Handout 1–3, "Lifetime Resource Calculations."

Answers to Student Handout 1–3

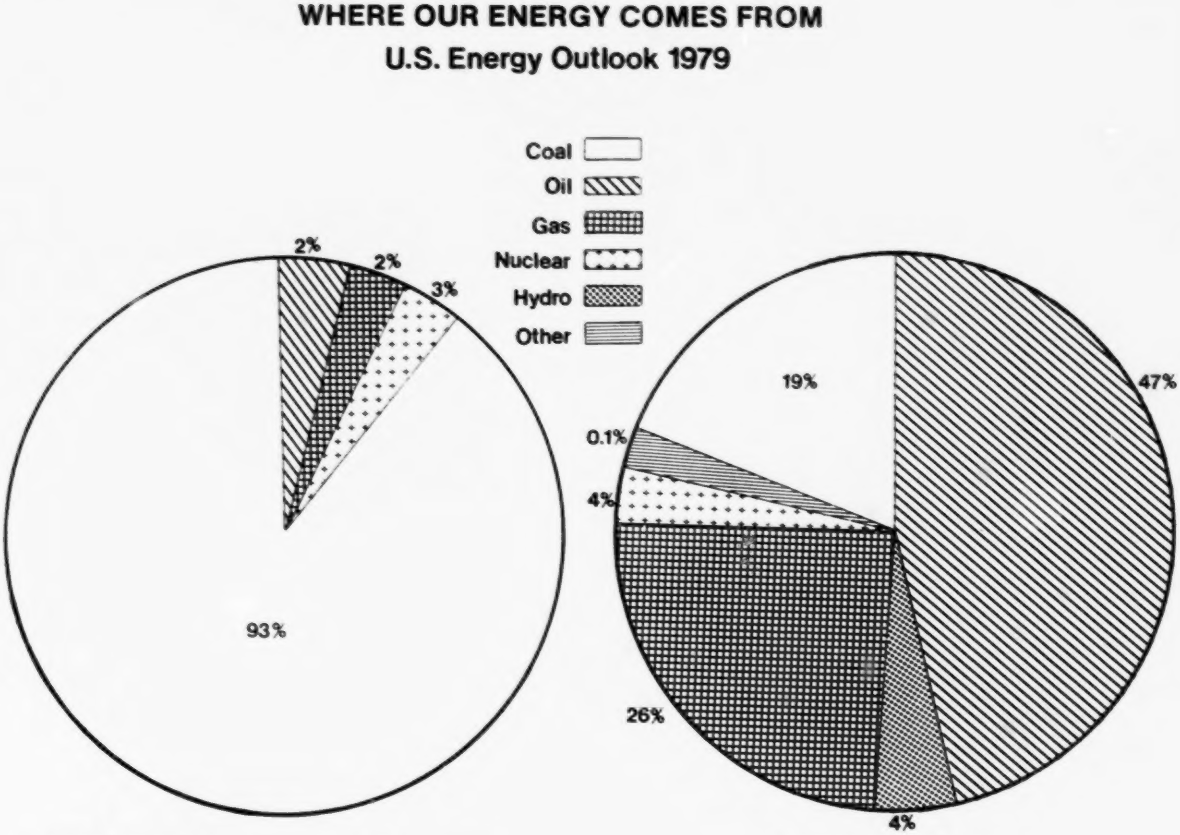
1. 85 million bbls/day × 365 days/year = 31 billion bbls/year.
   445 billion ÷ 31 billion = 14.4 years.
2. 500 billion ÷ 600 million = 833.3 years.
3. 500 billion ÷ 1 billion = 500 years.
4. 80 quads = $(80 \times 10^{15}) \div (2.62 \times 10^{7}) = (30.5 \times 10^{8}) = (3.05 \times 10^{9})$ or about 3 billion tons.
   500 billion ÷ 3 billion = 166.7 years.
5. The flaw is that neither reserves nor consumption rates remain constant. While these figures are based on current estimates, future exploration may lead to new resources or to an increase in reserves. On the other hand, conservation efforts may lower our consumption rate, or we may use new energy sources and shift away from oil, gas, and coal. Demand, conservation, economics, exploration, politics, and reserves are all interrelated.

Distribute Student Handout 1–4, "How We Use Energy." The graphs show energy consumption by sector. Students should identify the major sources of energy for each sector.

Answers to Student Handout 1–4

1. Oil. No, because coal is not a combustible liquid or gas.
2. It is relatively cheap and is the cleanest burning fuel. No. You would need a whole new heating system; pollution would become a major problem; and a new fuel distribution system would have to be implemented.
3. Change coal to synthetic oil or gas. Use coal to generate electricity, heat your home electrically, and use an electric car. Develop a car engine and a home heating system that burn solid fuel.

Student Handout 1–1
Where Our Energy Comes From (1979)



Total Recoverable Non-Renewable Resources

Consumption Pattern

Use the information in the graph to answer these questions.

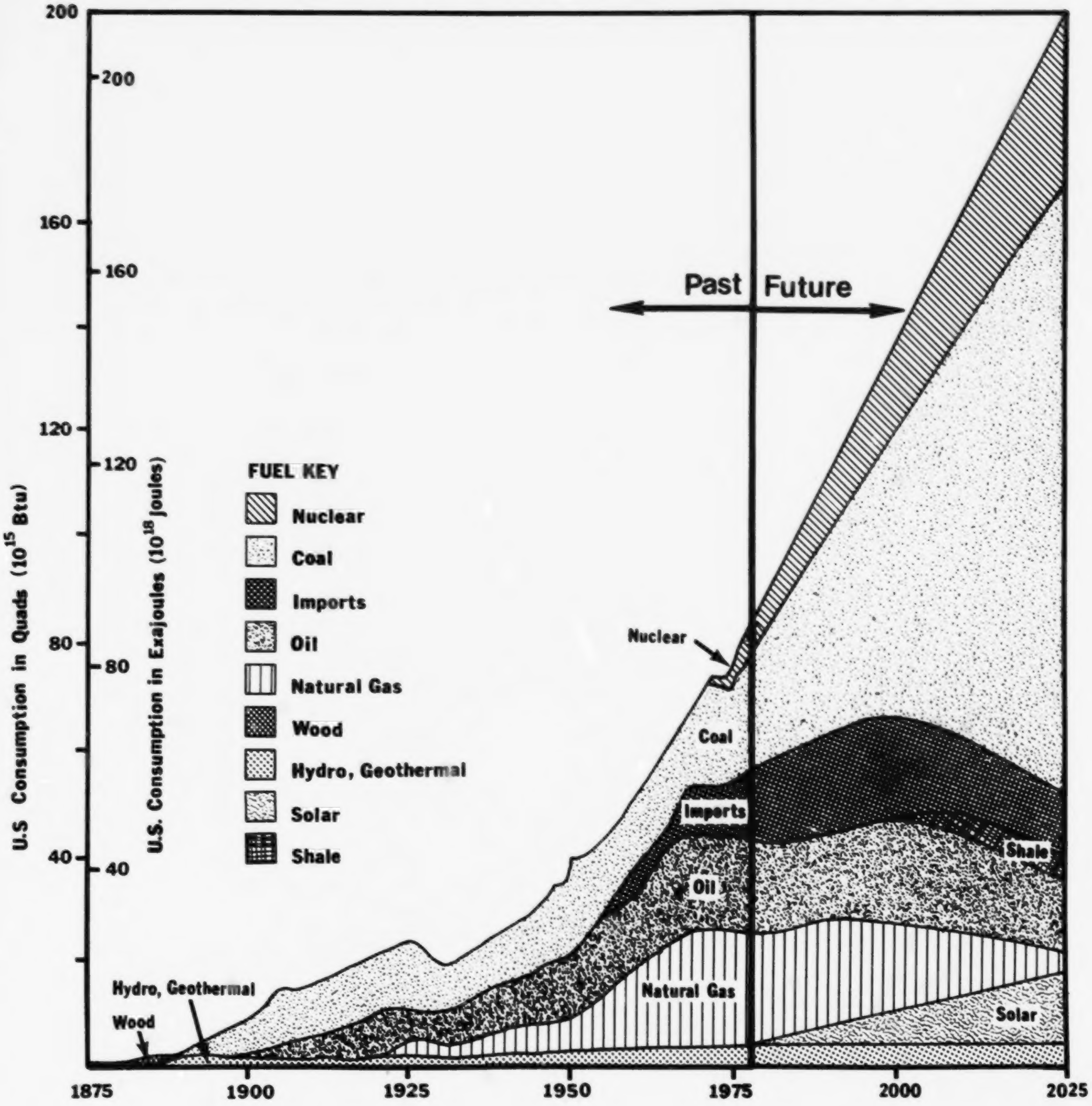
1. Of which energy source does the U.S. consume the most? What percent of our reserves does this source represent?
2. How much coal does the U.S. consume? What percent of our reserves does coal represent?
3. How much natural gas does the U.S. consume? What percent of our reserves does natural gas represent?
4. Which two sources combined supply 8 percent of the energy we consume? One of these is shown on the resource graph. What percent of our reserves does it represent? Why isn't the other shown on the resource graph?
5. Use your answers to the questions above to write a short paragraph summarizing the energy situation in the United States. What change(s) would you suggest to improve the situation?

Student Handout 1–2
The Kink in Our Quest for the Good Life

This graph shows a concise energy history of the United States. Examine it carefully and answer the following questions. **Note:** Quad is short for quadrillion or 10^{15} Btu. One quad is equal to: 170 million barrels of crude oil; 7 billion gallons of crude oil; 43 million tons of bituminous coal; 1 trillion cubic feet of natural gas; 293 billion kilowatt hours of electricity; 393 billion horsepower.

1. What was our principal energy source in 1875? In 1910? Which two in 1960?

The Energy History of the United States



2. What new factor became significant in the 1960s that allowed our energy consumption to continue to grow?
3. What general shape does the energy demand curve have?
4. Assuming 1875 to be almost zero quads, how many years did it take the U.S. to grow, decline, and grow again to a 20 quad economy?
5. How many years did it take to double, becoming a 40 quad economy?
6. How many years did it take to double again, becoming an 80 quad economy?
7. What is the average doubling time from 1875–1975? (Use your answers to the last three questions.)

8. The equation that relates doubling time to percent annual growth rate is:

$$\text{Doubling Time in Years} = \frac{70}{\text{\% Annual Growth Rate}} \quad \text{or}$$

$$T_2 = \frac{70}{R}$$

Using this equation, find the approximate percent of annual increase in American energy consumption since 1875.

9. Suppose we continue to grow at the rate you calculated in question 8. How many times would energy consumption double in 100 years? At that rate, how much energy would be consumed in the year 2075?
10. Support or criticize the following statement: *The United States can continue to consume energy at the rate it has for the last hundred years for the next hundred years, and probably can do it forever.*

Student Handout 1-3
Calculating Resource Lifetimes

Use the following formula to answer the questions below.

$$\text{Lifetime} = \frac{\text{Reserve}}{\text{Constant Rate of Use}}$$

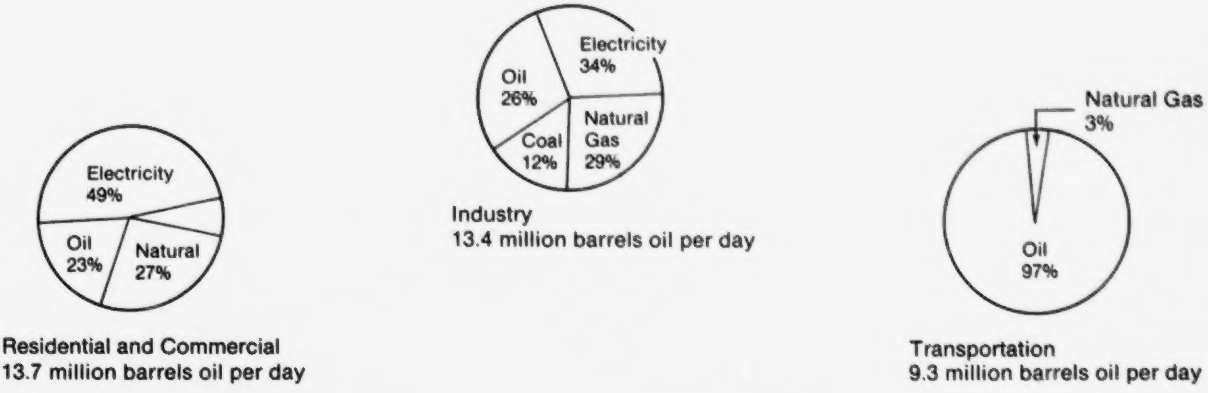
1. Global reserves of petroleum total roughly 455 billion barrels. It is estimated that the world appetite for oil may reach 85 million barrels a day in the 1990s. At that consumption rate, how long will the world reserves last?
2. Currently the U.S. has a reserve of about 500 billion tons of coal that can be mined economically using existing technology. Current coal production is about 600 million tons per year. Use these two facts to calculate how long our coal reserves will last under current conditions.
3. Some experts advocate coal production of 1 billion tons per year. At that rate, how long would our coal last?
4. The *total* energy consumption of the United States in 1979 was almost 80 quads. Coal has an energy content of approximately 2.62×10^7 Btu/ton. If it were possible to power the whole country using coal, how many tons of coal would we require? At the yearly consumption rate you calculated above, how long would 500 billion tons last?
5. What is the primary flaw in all of these calculations?

Student Handout 1-4
How We Use Energy

Use the information in the graphs to answer these questions.

1. What is the major fuel used in transportation? Can coal be directly substituted for it? Why or why not?
2. The preferred fuel for heating homes and buildings is natural gas. Why is it a good fuel? Can coal be directly substituted for this fuel? Why or why not?
3. Name three ways you could use coal to run your car or heat your house.

U.S. Energy Consumption by Sector, 1979



Residential and Commercial
13.7 million barrels oil per day

Industry
13.4 million barrels oil per day

Transportation
9.3 million barrels oil per day

Lesson 2

The First Law of Thermodynamics

Energy can be neither created nor destroyed, only converted to different forms. This is the First Law of Thermodynamics. In order to allow students to understand the development of this law, this lesson uses several examples of proposed perpetual motion machines. Students should determine that in each, energy is being converted, but that there is no evidence that it has been created. Students search for evidence to decide whether the energy has ultimately been destroyed.

OBJECTIVES

Students should be able to:

- Identify locations in a machine where energy is converted from one form to another.
- Recognize that machines are *open systems* through which energy can enter and leave.
- Explain why perpetual motion is not possible.
- State the First Law of Thermodynamics.
- Use the First Law to evaluate schemes to generate more energy.

TARGET AUDIENCE

Students of Chemistry and Physics

TIME ALLOTMENT

One class period

MATERIALS

Student Handout 2-1, "The First Law of Thermodynamics"
Student Handout 2-2, "Will These Machines Produce More Energy Than They Use?"

TEACHING STRATEGIES

Distribute Handout 2-1. Mention that these machines are discarded solutions and ideas. Ask students to examine each machine for flaws that will stop the motion.

A second approach might involve dividing the class into marketing teams charged with the responsibility of selling one of the machines to the rest of the class.

No matter which method is used to introduce the lesson, the discussion should focus on the flaws in the machines that prevent the achievement of perpetual motion. These flaws always involve energy conversions that are either overlooked or misinterpreted. The energy conversions exist regardless of the design of the machines. The machines, then, are *closed systems* which cannot (a) be set in motion without input energy from outside the system (thereby opening the closed system), and which cannot (b) continue to move, because of energy "losses"* from the system to the environment (another opening of the closed system).

The discussion outlined by the following questions prepares the students for the articulation of the First Law of Thermodynamics. For each example, first ask the students to imagine how the machine was intended to work, then ask:

1. Where does the energy to set the machine in motion come from? (In Machine A, someone has to turn the wheel; in Machine B, someone must roll the ball down the ramp; in Machine C, someone must introduce the water to the top trough. The key concepts are *energy input* and *from outside the system*; without these two conditions, the machines will not start.)
2. What energy source is being used at the point of input? (In all three cases, gravitational potential energy is being used.)
3. Locate some places in the machine where this input energy is converted to kinetic energy of motion. (Machine A: where the balls strike the spokes of the wheel. Machine B: where the ball rolls down the ramp. Machine C: where the falling water hits the waterwheel; where the wheel's shaft turns the gear; where the water is pumped up to the trough.) State the terms of these conversions. (They move from gravitational potential energy to kinetic energy or energy of motion.)
4. Are other energy conversions taking place at the same time that do not contribute to the motion of the machine? (Yes.) Can you locate some places where these conversions occur? (Many of the same places where the conversions to the energy of motion are occurring.) What causes conversions? (Friction of various kinds.) State the terms of these conversions. (From the energy of motion to heat energy.)
5. What happens to the energy converted at these points? (It is wasted; it leaves the system, or is dissipated; this dissipation is referred to as "energy loss.") Does it continue to exist or has it been destroyed? (The energy continues to exist in the form of heat; because this form of energy does not produce motion in these examples, it may *appear* to have been destroyed. (Its effects are difficult or impossible to see, but careful measurement can theoretically account for all energy losses in any given situation.)
6. Can the machine itself supply any energy to offset the effect of these conversions that do not contribute to the motion of the machine? (No, these machines are passive, they cannot create energy.)
7. What would have to happen for the machine to continue moving after all the identified energy conversions have taken place? (More energy from outside the system would have to be introduced into the machine.)
8. Summarize the outcome of this discussion by explaining why, in any closed system, perpetual motion is impossible. (A perpetual motion machine is supposed to run endlessly on only the amount of energy required to set the machine in motion [input energy]. Because some of the input energy is converted into a form that does not contribute to the motion of the machine ["energy loss"], and because the machine cannot supply or create additional energy to make up for the energy loss, the motion eventually stops.)

Answers to Student Handout 2-1

Machine A: Answers will vary. However, students should point out that energy is lost because some is used to overcome the friction of the wheel and axle and some is converted to heat by the impact of the balls. Since all the energy comes from the falling balls, there is not enough to raise them up again.

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*For simplicity we will continue to speak of energy loss, but both the teacher and the student must remember that it is only lost from usefulness, not absolutely lost.

Machine B: If the magnet is strong enough to lift the ball all the way up the ramp, it is strong enough to hold it there and keep it from falling.

Machine C: Answers will vary. However, students should point out that energy is "lost" because some is used to overcome friction of the moving parts. After these losses there is not enough energy to lift the water back to its original height, let alone to grind wheat.

Tell your students that they have just described the First Law of Thermodynamics. Write the First Law on the chalkboard: "Energy can be neither created nor destroyed. It can only be changed from one form to another."

Evaluate students' understanding of the First Law of Thermodynamics by their analysis of another set of drawings. Two schemes for generating additional energy from a moving automobile are shown in Student Handout 2-2.

The first picture shows a truck traveling along a highway using mechanical energy to generate electricity which is then put in a storage battery.

The second picture shows an automobile with a windmill mounted on top. This windmill is turning in the wind caused by the car's motion and charging the batteries.

Ask students to write an answer to this question: "Do you think this machine will generate useful (additional) energy? Why or why not?" Apply the question to both machines.

Answers to Student Handout 2-2

Machine A: No, it won't. Reason: It can't produce more energy than was used to turn the wheels in the first place. Some energy is lost to overcome friction—wheels produce friction through contact with the road, in bearings, etc.

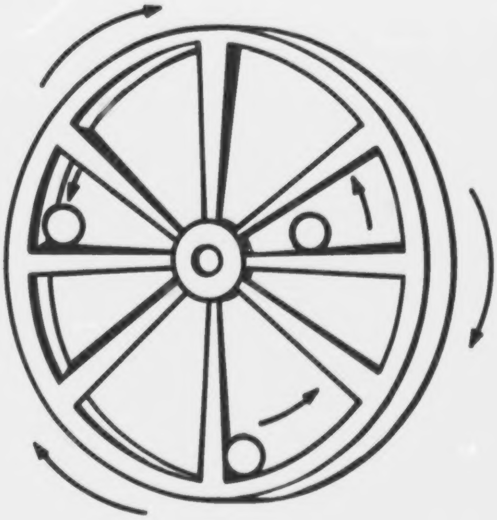
Machine B: No, it won't. Reason: Much of the engine's energy is lost in overcoming friction and wind resistance. If the students mention that more energy can be produced by making the car go faster, ask whether speeding up will take more energy and result in more wind resistance, eventually slowing the car down. If the wind is blowing and the car is sitting still, the windmill might produce energy. When the car is moving, most of the energy to turn the windmill comes from the car itself.

Student Handout 2–1

The First Law of Thermodynamics

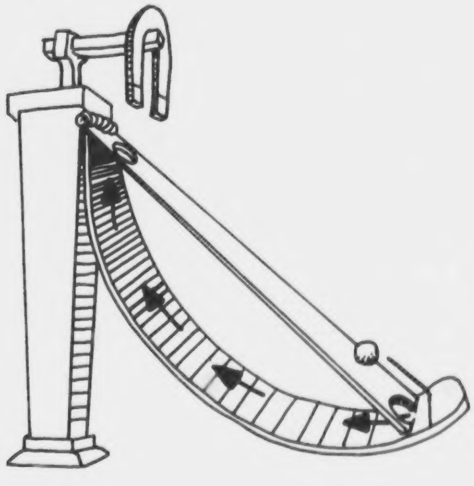
Look carefully at the machines on this page and read the descriptions. Then point out the flaw in each machine. Use your own paper for your remarks.

Machine A



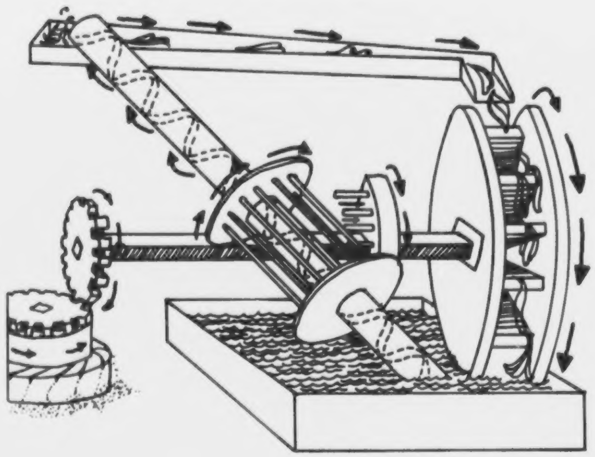
The machine above is started by hand. The balls roll to the end of the compartments where their torque causes the wheel to turn as shown. (Torque is the product of the balls' weight times the distance from the balls' position to the axle.) The direction of motion of the balls is shown by the small arrows.

Machine B



In this machine the magnet draws the ball up the straight ramp. It then falls through the hole at the top, rolls down the curved ramp, and is drawn back up again.

Machine C



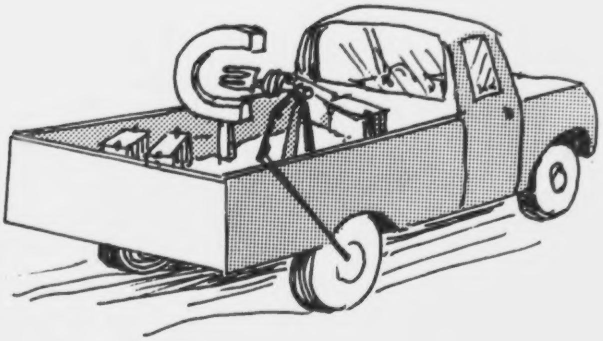
In this machine, water falling from the top trough turns the waterwheel with a shaft turning a gear. The gear operates a pump (called the Archimedes screw) which moves more water up to the top. At the same time, a second gear moves a grindstone to make flour.

Student Handout 2–2

Will These Machines Produce More Energy Than They Use?

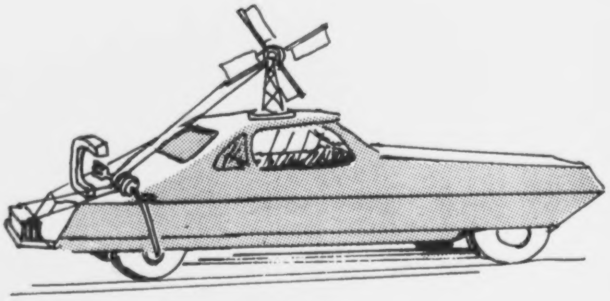
Explain why you think these machines will create more energy than they use. If you don't think they will work, tell why.

Machine A



Engine turns wheel, which turns generator, generator charges battery, battery runs engine.

Machine B



Wheels turn, car moves forward, air pressure turns windmill, windmill turns generator, generator charges battery, battery runs engine, engine turns wheels.

Lesson 3

The Basis for Nuclear Power

The energy that binds atoms can be released for other purposes by nuclear fission. To help students understand how energy is stored in the nuclei of atoms, this lesson includes some examples that students will find familiar. They learn terminology associated with atomic nuclei and the changes nuclei undergo in producing nuclear energy. Students also learn the three decay processes that radioactive nuclei can exhibit.

OBJECTIVES

Students should be able to:

- Explain the tendency of systems to become more tightly bound.
- Using an oil drop model, explain how fission releases nuclear energy.
- Using a set of mousetraps or dominoes, demonstrate the principle of a chain reaction.
- Write equations showing changes in nuclei when nuclear energy is released.
- Identify the different types of radioactivity.

TARGET AUDIENCE

Students of Chemistry, Physics, Physical Science

TIME ALLOTMENT

Three to five class periods

MATERIALS

Student Handout 3-1, "The Basics of Nuclear Fission: A Review"
Student Handout 3-2, "Energy Stored in the Nucleus"
Student Handout 3-3, "An Oil Drop Model of a Fissioning Nucleus"
Student Handout 3-4, "Modeling a Chain Reaction"
Student Handout 3-5, "Random Order of Nuclear Fission"
Student Handout 3-6, "Nuclear Reactions Worksheet"
Student Handout 3-7, "Radioactivity Game"

Activity 1
  Drinking glass or beaker
  Rubbing alcohol (not less than 70% solution)
  Cooking oil
  Water
  Teaspoon
  Butter knife
  Paper towel

Activity 2
  32 mousetraps
  String
  Set of dominoes

Activity 3
  32 mousetraps
  64 corks

Activity 4
  Chart of the nuclides
  Dice
  Game board tokens

TEACHING STRATEGIES

Have students read Student Handout 3-2, "Energy Stored in the Nucleus," before the first class period. If the students are not comfortable with the terminology of nuclear structure they should first read Student Handout 3-1, "The Basics of Nuclear Fission: A Review."

Activity 1

In this activity, a drop of salad oil suspended in a mixture of alcohol and water will represent a nucleus. By prodding and splitting the drop of salad oil with a butter knife, students can demonstrate the types of changes a nucleus undergoes in fission. This activity also illustrates the theory of surface tension. Directions for this experiment and a follow-up set of questions are provided in Student Handout 3-3, "An Oil Drop Model of a Fissioning Nucleus." The questions may be more appropriate for group discussion than for individual assignments.

Answers to Student Handout 3-3

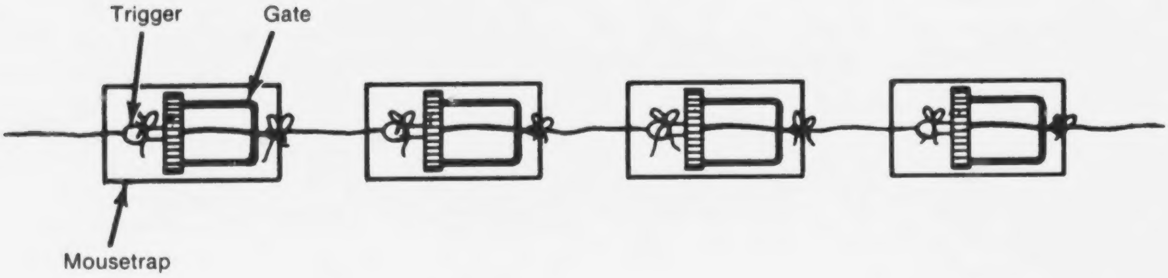
a. The oil drop is held together by electromagnetic forces; its shape is spherical.
b. The earth is held together by gravitational forces; its shape is that of an oblate spheroid—a sphere bulging at the middle because of its rotation.
c. The nucleus is held together by strong nuclear forces. Some nuclei behave as if they are spherical. Others behave as if they rotate and have shapes of oblate and prolate spheroids.

Activity 2

Students work with arrangements of mousetraps or dominoes to demonstrate the concepts of chain reactions and critical mass. While certain aspects of a chain reaction can be shown with dominoes, mousetraps are more flexible in demonstrating the random order in nuclear fission. Because of the equipment required and the precautions that must be taken, this is probably best done as a group (rather than as an individual) activity, under close teacher supervision. Student Handout 3-4, "Modeling a Chain Reaction," gives directions for the experiments and follow-up questions.

Answers to Student Handout 3-4

1. Students should record that all the traps go off. It's a runaway reaction.
2. B
3. D
4. A
5. C
6. Tipping over a domino.
7. The traps are arranged so that the springing of one will spring only *one* additional mousetrap.



8. Arrange the dominoes in a row. This way, tipping over the first domino will tip the second; the second will tip the third; and so on.
9. (b) Critical; the reaction merely sustains itself.
10. Supercritical. The reaction is out of control—it represents the explosion of an atomic bomb.

Activity 3

Have students set up an arrangement of mousetraps and follow the procedure outlined in Student Handout 3-5, "Random Order of Nuclear Fission." This activity demonstrates that in an actual reactor, the sequence in which nuclei are fissioned is more random than the chain reaction in Activity 2. Students should answer the questions after the demonstration.

Answers to Student Handout 3-5

1. Students will probably say that most of the traps spring; however, the number of sprung traps may vary.
2. A neutron.
3. Student answers may vary. If all traps sprang, they represent a critical or supercritical mass.
4. Students will probably state that more traps should spring because the "fence" reflects corks that would otherwise escape.
5. a. Student answers will vary.
   b. Student answers will vary.
6. A smaller percentage should spring, because there is now "dead space" between the mousetraps for the corks to hit. There are also fewer traps to trigger.
7. Student answers will vary.
8. Answers will vary.
9. The percentage that spring depends on the number of traps as well as their density.
10. When using 16 traps, a smaller percentage should spring than when 32 traps were used. There is more "empty space" around a smaller number of traps into which corks can escape.

OPTIONAL

Answers will vary. The flypaper acts as a moderator, a component of nuclear reactors. Distribute Student Handout 3-6, "Nuclear Reactions Worksheet", for students to do as homework.

Answers to Student Handout 3-6

1. ${}^{17}_{8}\mathrm{O}$
2. ${}^{1}_{0}\mathrm{n}$
3. ${}^{235}_{92}\mathrm{U}$
4. ${}^{233}_{90}\mathrm{Th}$
5. Equations are:

$$ {}^{1}_{0}\mathrm{n} + {}^{232}_{90}\mathrm{Th} \rightarrow {}^{233}_{90}\mathrm{Th};\quad {}^{233}_{90}\mathrm{Th} \rightarrow {}^{233}_{91}\mathrm{Pa} + {}^{0}_{-1}\beta + {}^{0}_{0}\nu $$

$$ {}^{233}_{91}\mathrm{Pa} \rightarrow {}^{233}_{92}\mathrm{U} + {}^{0}_{-1}\beta + {}^{0}_{0}\nu $$

6. ${}^{92}_{36}\mathrm{Kr}$
7. ${}^{3}_{2}\mathrm{He}$
8. a. ${}^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + {}^{0}_{0}\nu$ + energy (beta decay)
   b. ${}^{4}_{2}\mathrm{He}$ (alpha decay)
   c. ${}^{0}_{-1}\beta + {}^{0}_{0}\nu$ + energy (beta decay)
   d. energy (gamma ray-gamma decay)
   e. ${}^{4}_{2}\mathrm{He}$ (alpha decay)
   f. ${}^{0}_{-1}\beta + {}^{0}_{0}\nu$ + energy (beta decay)

Activity 4

Rules of play for the game are given in Student Handout 3-7, "Radioactivity Game." Distribute the game rules to your students and divide the class into groups of 6–8 students. To each group give one die, one game board, and marking tokens for each student. The game board consists of the portion of the chart of the nuclides connecting ${}^{240}_{94}\mathrm{Pu}$, ${}^{237}_{93}\mathrm{Np}$, ${}^{241}_{95}\mathrm{Am}$, ${}^{238}_{92}\mathrm{U}$, ${}^{242}_{96}\mathrm{Cm}$, ${}^{243}_{96}\mathrm{Cm}$, and ${}^{239}_{92}\mathrm{U}$ to their ultimate decay products: ${}^{208}_{82}\mathrm{Pb}$, ${}^{209}_{83}\mathrm{Bi}$, ${}^{206}_{82}\mathrm{Pb}$, and ${}^{207}_{82}\mathrm{Pb}$. This can be laid out on a sheet of poster board. If possible, draw different colored arrows to illustrate each of the four radioactive decay chains. To conclude the game, have students review the four nuclear chains by writing them on the chalkboard. Emphasize the four stable terminating isotopes, ${}^{206}_{82}\mathrm{Pb}$, ${}^{207}_{82}\mathrm{Pb}$, ${}^{208}_{82}\mathrm{Pb}$, and ${}^{209}_{83}\mathrm{Bi}$.

SOURCES

Benrey, Ronald M. *Nuclear Experiments You Can Do . . . From Edison*. Thomas Alva Edison Foundation, Southfield, MI, 1976. (Teachers can obtain free copies of this booklet by writing the Thomas Alva Edison Foundation, Suite 143, Cambridge Office Plaza, 18280 West Ten Mile Road, Southfield, MI 48075.)

Duderstadt, J.J. and C. Kikuchi. *Nuclear Power: Technology on Trial*. The University of Michigan Press, Ann Arbor, 1979.

Inglis, David R. *Nuclear Energy: Its Physics and Its Social Challenge*. Addison-Wesley, Reading, MA 1973.

NOTE

J.L. Roeder, "Throwing Dice in the Classroom," *The Physics Teacher* 15, 428 (1977). Copyright American Association of Physics Teachers. Used by permission.

Student Handout 3-1

The Basics of Nuclear Fission: A Review

The energy that ultimately appears as the electrical energy carried from nuclear power plants by high voltage transmission lines is produced through conversion processes that begin with the fissioning of the nucleus of one of the heaviest atoms, uranium.

The center of the atom is called the nucleus. There are two types of particles, the *proton* and the *neutron*, in the nucleus. The proton and the neutron have about the same mass (the neutron has slightly more), but only the proton has an electric charge, which is positive. Because each particle contributes about the same mass to the nucleus, the mass of the nucleus can be approximated by counting the particles. The sum of the protons and neutrons is called the *mass number*. The number of protons is known as the *atomic number*. The atomic number also equals the number of negatively-charged *electrons* surrounding the nucleus of a neutral atom. The arrangement of these electrons in the atom determines its chemical properties. Although electrons have a very small mass (about 1/2000 that of a proton), their electric charge is very important. It binds them to the nucleus and balances the nucleus' charge, so that the net electric charge on the atom is zero.

We can identify an atom by the following notation:

$^{238}_{92}U$

238=mass number
U=symbol for the chemical element
92=atomic number

238 U is read as "uranium-238"; it may also be written this way.

This notation tells us that this nucleus of uranium contains 92 protons, the atomic number. To figure how many neutrons in the nucleus, simply subtract the number of protons from the mass number, the sum of neutrons and protons: 238-92=146 neutrons. The atomic number also tells us that 92 electrons surround this nucleus in a uranium atom.

All nuclei of uranium contain 92 protons. This is what makes the nucleus unique to uranium.* However, there is no such restriction on the number of neutrons in a nucleus. Although the number of neutrons is greater than the number of protons in most cases, it may vary from one nucleus of a given chemical element to another. For example, most nuclei of uranium are $^{238}_{92}U$. Atoms of a chemical element with nuclei containing a different number of neutrons are called *isotopes*.

How many neutrons does a nucleus of $^{235}_{92}U$ contain? How many protons? How many electrons surround this nucleus in an atom? Again, the number of protons and electrons is the atomic number 92. To find the number of neutrons, subtract the number of protons from the mass number: 235-92=143.

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*Although the atomic number subscript is repetitive, we shall continue to use it, because it is a useful record-keeping device.

Student Handout 3-2

Energy Stored in the Nucleus

ENERGY STORAGE

When discussing energy sources, we often talk about "producing" energy that people will "consume." Because the law of conservation of energy tells us that energy can be neither created nor destroyed, what we are actually doing is converting energy from one form to another.

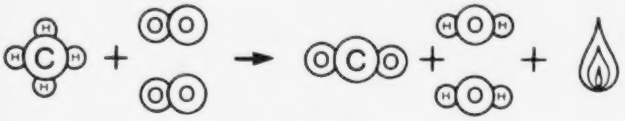
When energy is "produced" it is often converted from a form that is "stored" potential energy into another form, such as heat. Heat can then be converted in an engine to mechanical energy and be used to produce motion. This in turn can be converted by a generator to the energy of an electric current. In the case of hydroelectric power, the potential energy of the water behind the dam is converted directly into the motion of the turbines and the generators.

How can energy be stored? Energy is stored, for example, in water behind a dam. The water is held by the dam at a higher level (farther away from the center of the earth). If allowed to run over or through the dam, it drives a turbine and moves to a lower level (closer to the center of the earth). At the lower level, the earth's gravitational force on the water is stronger and the water is more tightly bound to the earth.

Potential energy can also be stored in a spring. If a spring is deformed—stretched or compressed—energy is stored in it that will be given up when it returns to its normal shape; the one in which molecules are in the most tightly bound position. This illustrates the key to potential energy: if a system has the ability to rearrange itself into a more tightly bound configuration, the potential or stored energy can be "released" from the system and converted to another form. Thus, the water rearranges its position to become closer to the earth and hydroelectricity is generated from the mechanical energy rearrangement provided.

When the water moves from a higher to a lower level, what is the source of the energy that is released? The water had to be lifted to the higher level in the first place and it took energy to do this. That energy, of course, was the energy from the sun that evaporated the water. That energy is stored as potential energy that becomes available as the water runs back down the mountains and, by getting closer and closer to the center of the earth, becomes more tightly bound to it.

Fossil fuels: Most of the energy used today is stored in the fossil fuels—coal, oil, and natural gas. Fossil fuels consist of molecules in which atoms of carbon and hydrogen are chemically bonded to each other. When these fuels burn, their molecules react with molecules of oxygen in the air. The result is a rearrangement of atoms in these molecules into the more tightly bound molecules of water and carbon dioxide—and the release of energy in the form of heat. This is most simply illustrated in the case of natural gas, most of which is methane, CH_4.

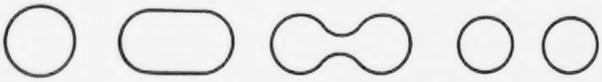


$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O + \text{heat}$

Again, it is potential energy that is released, in this case energy that was stored by photosynthesis in plants. The plant substances have been changed (by digestion or by long, involved geological processes) into methane, but the stored energy is still there to be released.

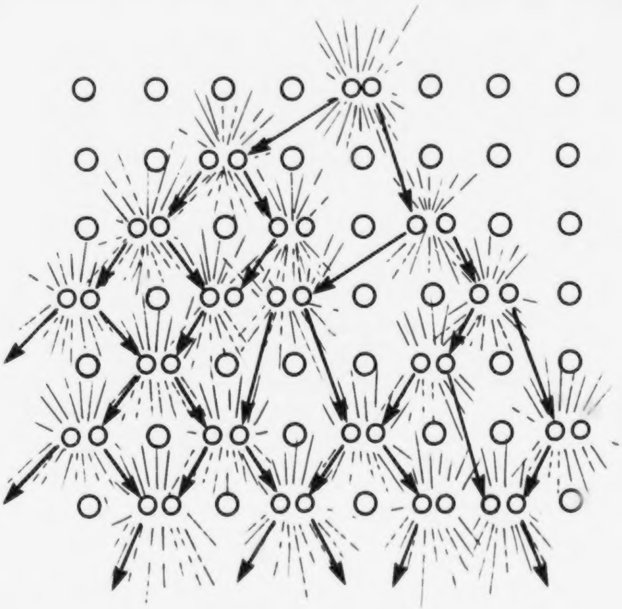
Energy from nuclear fission: Energy is released from the nuclei of atoms in a way that resembles the chemical example. Particles in atomic nuclei rearrange themselves into more tightly bound configurations. But the bonds between particles in a nucleus can store a million times more energy than the bonds between atoms in a molecule. Thus, the energy released per nuclear reaction is a million times greater than that released in chemical reaction. Moreover, in a chemical transformation a new molecule results. In a nuclear transformation, a new element results.

When particles in a nucleus rearrange themselves into more tightly bound configurations, what kind of rearrangement occurs? From the standpoint of producing energy, the most important rearrangement is the one that results when a *thermal neutron* strikes a nucleus of $^{235}_{92}U$. (Thermal neutrons are neutrons moving at speeds like those of molecules in the atmosphere.) When thermal neutrons hit nuclei of $^{235}_{92}U$, they give up such a large amount of energy to this nucleus that they can cause it to split, or *fission*. The fission of a uranium nucleus has been compared to the movement of a drop of liquid. If the movement is made sufficiently violent by adding energy, the drop may begin to vibrate and eventually divide itself into two smaller drops:



The fission products that remain after a nucleus of $^{235}_{92}U$ splits may not appear to be more tightly bound than the single original nucleus, but the neutrons and protons in those fission products are more tightly bound to each other. Thus the fission of $^{235}_{92}U$ releases energy.

Not only is energy released in the fission of $^{235}_{92}U$ by thermal neutrons; additional neutrons are released as well. What can these neutrons do? They can hit additional nuclei of $^{235}_{92}U$ and cause them to fission, thus releasing still more energy and still more neutrons. The result is known as a *chain reaction*.



When this chain reaction is allowed to build up beyond control, an explosive release of nuclear energy occurs. This is what happens in a nuclear weapon, an atomic bomb. When this chain reaction is controlled to release energy gradually, the heat produced can be usefully converted into motion and electric current. This is the purpose of a nuclear reactor.

Whether a chain reaction builds up beyond control or releases energy gradually is determined by whether the neutrons released in one fission process cause additional reactions. This, in turn, depends upon the speed of the neutrons (which governs their ability to cause fission) and the density of nuclei of $^{235}_{92}U$. If there are not enough nuclei of $^{235}_{92}U$ or they are too far apart, the neutrons will escape and the chain reaction will not sustain itself. In this case the mass of uranium is said to be *subcritical*. In a nuclear reactor, the chain reaction must be self-sustaining. Hence, a *critical mass* of uranium is required. To keep the chain reaction from building up beyond control (in which case the reaction becomes *supercritical*), the amount of uranium and the spacing between nuclei of $^{235}_{92}U$ must be controlled. It turns out that one of the greatest controls is nature herself: only one out of every 140 uranium nuclei is $^{235}_{92}U$. The other uranium nuclei, mostly $^{238}_{92}U$, are not fissioned by thermal neutrons. In fact, nuclei of $^{238}_{92}U$ are inclined to absorb thermal neutrons.

The absorption of neutrons in non-fissioning events (in other words, the capture of thermal neutrons) can also be enhanced artificially. *Control rods* containing materials such as boron or cadmium which have a large capacity for capturing neutrons can remove them from the flux available to cause fission. These control rods can be moved in or out of the region in which fission is occurring in a reactor.

Why are nuclei of $^{235}_{92}U$ fissioned by thermal neutrons while nuclei of $^{238}_{92}U$ are not? Recall that atoms of different elements have different chemical properties because they have different numbers of electrons. In the same way, nuclei of $^{235}_{92}U$ and $^{238}_{92}U$ have different *nuclear* properties, because they have different numbers of neutrons. Thus $^{235}_{92}U$ is the fissionable nucleus and it is the major source of energy in U.S. reactors. There are other fissionable nuclei, another form of uranium $^{233}_{92}U$ and plutonium $^{239}_{94}Pu$. These latter two do not exist in nature and are formed artificially.

We can summarize what happens in nuclear fission in the following way. A ${}^{235}_{92}U$ nucleus "captures" a thermal neutron, receiving enough energy to make it unstable. Eventually the nuclear instability makes it split roughly in half—it fissions. In fissioning, it releases a large amount of energy.

The two chunks of the nucleus—they are different elements—receive this energy as kinetic energy which quickly becomes heat as they collide with the surrounding atoms. It is this heat that comprises the energy output of the reactor fuel.

Because these two chunks of the split nuclei are unstable, they are not naturally occurring forms of the elements. They are therefore *radioactive*—they give off energy and energetic particles. It is these fission products that form the radioactive waste of nuclear reactors.

RADIOACTIVITY

The existence of these radioactive by-products make a nuclear reactor different from most other sources of energy. Below is a brief review of the three forms of radioactivity: alpha decay, beta decay, and gamma decay.

Alpha Decay: If undisturbed, a uranium nucleus will eventually decay, giving off a combination of two protons and two neutrons known as an *alpha particle*. This process is one form of *radioactivity*, or *radioactive decay*, known as *alpha decay*.

What is left after alpha decay of the uranium nucleus? Note that the alpha particle, with two protons and two neutrons, has a mass number of 4. With two protons, it also has an atomic number of 2 and is in fact the nucleus of the helium isotope, ${}^{4}_{2}He$. To find out what is left, we simply calculate the mass and atomic numbers. For ${}^{238}_{92}U$, the new mass number is 238–4=234, and the new atomic number is 92–2=90. Thus we have left the nucleus of the thorium isotope ${}^{234}_{90}Th$; this is called *daughter nucleus*. The daughter nucleus from the alpha decay of ${}^{235}_{92}U$ is determined in the same way to be ${}^{231}_{90}Th$. The decay of ${}^{235}_{92}U$ would be the same as that of ${}^{238}_{92}U$, except that there are fewer neutrons.

Energy is also released from alpha decay along with the alpha particle and daughter nucleus. But the rate at which this energy is released is very slow, too slow to provide energy in useful concentrations. In the 4½ billion years since the solar system was formed, only one half of all the ${}^{238}_{92}U$ has decayed; and it will take another 4½ billion years for half of the remainder to decay. For this reason, 4½ billion is called the *half life* of ${}^{238}_{92}U$. (Other nuclei have different half lives. For example, ${}^{235}_{92}U$ has a half life of 713 million years.)

Beta Decay: When nuclei of ${}^{238}_{92}U$ absorb neutrons, nuclei of ${}^{239}_{92}U$ are formed. This is part of the reaction which eventually forms the ${}^{239}_{94}Pu$ we have mentioned. Nuclei of ${}^{239}_{92}U$ exhibit a different form of radioactive decay called *beta decay*. In this decay a neutron in the nucleus changes into a proton, a *beta particle* (which is just a fast *electron*) and a *neutrino*. The beta particle and neutrino carry off most of the energy that is released, leaving a proton behind as a replacement for a neutron in the daughter nucleus. Since the beta particle is a fast electron, it has a negative charge and almost no mass and can be indicated as ${}^{0}_{-1}\beta$. The neutrino has neither mass nor charge and can be indicated as ${}^{0}_{0}\nu e$. Thus, the beta decay of ${}^{239}_{92}U$ can be written as follows:

$${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}\beta + {}^{0}_{0}\nu + \text{Energy}$$

(Remember this is an equation for the *nuclei* and says nothing about the atomic electrons.)

This decay proceeds rather quickly; the half life is 2.3 days.

$$\text{Nuclei of } {}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}\beta + {}^{0}_{0}\nu + \text{Energy}$$

Nuclei of ${}^{239}_{93}Pu$ are significant in that they, like nuclei of ${}^{235}_{92}U$, can also be fissioned by thermal neutrons. These nuclei are said to be *fissionable*. Because the ${}^{238}_{92}U$ nuclei serve as a starting point for making fissionable nuclei, ${}^{238}_{92}U$ is said to be *fertile*.

Gamma Decay: A third and final form of radioactive decay is *gamma decay*, marked by the emission of a *gamma ray*. Gamma rays are electromagnetic waves, similar to light rays but of a much higher frequency. They are pure energy; they have no mass as such. They are emitted by fission fragments or daughter nuclei from alpha and beta decay that are left in an "excited" state. These "excited" nuclei will emit gamma rays in the same way that atoms with "excited" electrons emit light rays (as in a fluorescent light bulb).

Student Handout 3–3

An Oil Drop Model of a Fissioning Nucleus

As you read in "Energy Stored in the Nucleus," the fissioning nucleus can be likened to the splitting of a drop of liquid. Why is this a good comparison?

Suspend a drop of salad oil in a mixture of alcohol and water. Then poke it with a knife and try to split it.

1. First, fill a glass about half full of rubbing alcohol. Then add enough water to fill the glass two-thirds full. Stir the mixture with a teaspoon. Then wipe the teaspoon dry and fill it with cooking oil.
2. Carefully bring the spoon close to the surface of the alcohol-water mixture, then gently tip the spoon over. A single blob of oil should slide into the glass.
3. If the blob floats on the surface, carefully add a bit more alcohol to the mixture. If it sinks to the bottom of the glass, spoon in some more water.
4. Now try to change the blob into an oil drop. Make it hover somewhere in the middle of the glass. (See diagram)
5. Take a knife and carefully prod the oil drop apart. Does the drop bulge before it breaks into two oil drops? Are the two new oil drops perfectly round? The oil drop "nucleus" split into two smaller "nuclei." But did the drop split before it was deformed by the knife? What can this tell you about the way all nuclei behave?
   a. What forces hold the oil drop together? What is its shape?

b. What forces hold the earth together? What is its shape?
c. What forces hold the nucleus together? What might you expect a nucleus' shape to be?

This experiment is one of eight contained in the publication, *Nuclear Experiments You Can Do . . . From Edison*. This booklet is available from the Thomas Alva Edison Foundation, 18280 West Ten Mile Road, Suite 143, Southfield, Michigan 48075, at $0.75 each or three for $2.00.

Student Handout 3-4

Modeling a Chain Reaction

THE MOUSETRAP CHAIN REACTION

Perhaps you can demonstrate how the fission of one nucleus also emits neutrons that can fission additional nuclei by rigging a mousetrap so when it is sprung, additional mousetraps are sprung as well.

Attach a string to the trigger for one trap (see diagram below). Then attach strings from the gate of the first trap to the triggers of two more traps. Attach strings from the gates of these two traps to the triggers of four more traps. Continue until you have used all the mousetraps. Be sure the strings are fairly tight; if they are not, the first trap may not spring the others. Spring the first trap.

1. What happened?

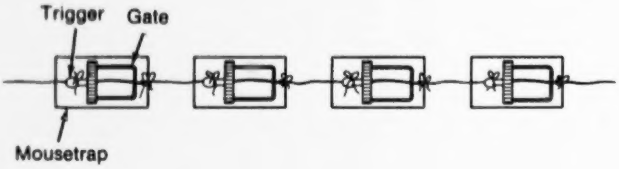
Match the component of the chain reaction of nuclear fission with the corresponding component of the mousetrap system.

NUCLEAR FISSION	MOUSETRAP SYSTEM
2. neutron	A. mousetrap
3. fissioning a nucleus	B. string
4. fissionable nucleus	C. potential energy of mousetrap
5. energy available from fission	D. pulling a string

TIPPING OVER THE DOMINOES

Can you simulate a chain reaction by arranging a set of dominoes? How would you set them up?

6. What represents the fission of a nucleus in a domino arrangement?
7. The chain reactions of the dominoes and the mousetraps illustrate "runaway" reactions that could get out of control. In a nuclear reactor, the sequence of fission is controlled to release energy gradually. How does the mousetrap arrangement below show a controlled reaction?



8. Write an explanation or draw a picture to show how you would rearrange the dominoes to demonstrate a controlled reaction.
9. Does the sequence of mousetraps in the arrangement in question 2 represent a mass of uranium that is (a) subcritical (b) critical, or (c) supercritical? Why?
10. How would you describe the mass of uranium represented by the mousetrap arrangement used at the beginning of this lesson—subcritical, critical, or supercritical? Why?

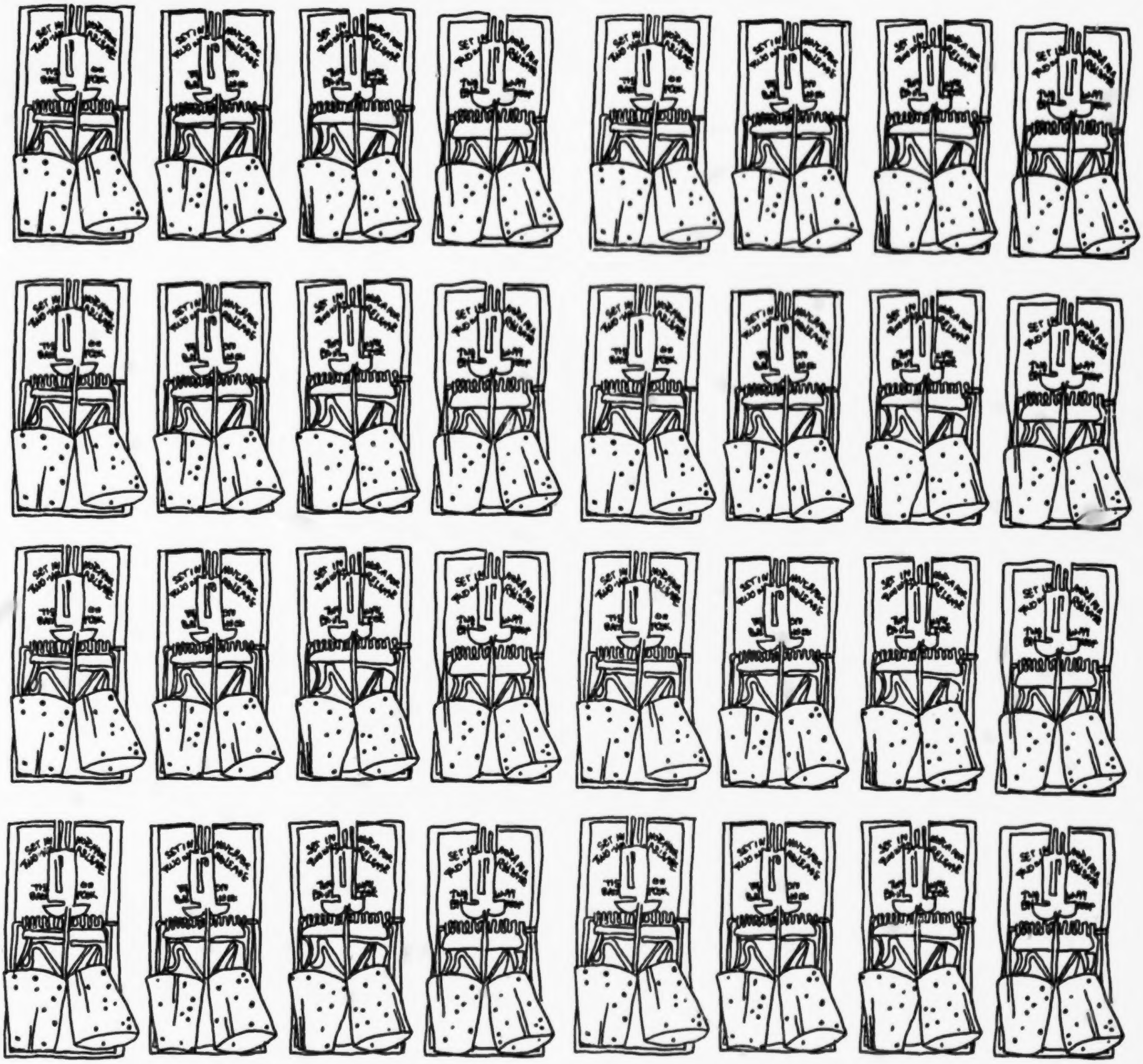
Student Handout 3-5

Random Order of Nuclear Fission

The arrangements of mousetraps and dominoes we have seen so far represent sequences of fissions with known orders of fissioning. In an actual reactor the sequence in which nuclei are fissioned is more random. You can demonstrate this by assembling and setting mousetraps in a regular arrangement with two corks mounted on each gate, as shown in the picture below. Toss in a cork and answer the questions that follow.

CAUTION: MOUSETRAPS ARE EXTREMELY SENSITIVE. DO NOT PLACE YOUR FINGERS IN THE WAY OF THE GATE. ALSO, DO NOT LOOK DIRECTLY DOWN AT THE TRAPS WHEN CORKS ARE SET ON THEM. WHEN A TRAP SPRINGS, IT CAN THROW A CORK AS HIGH AS 1.5 m.

1. What happened? (Note: if nothing happened, toss in another cork. Repeat this process until something happens.)
2. What does each cork represent?
3. Did the "happening" represent a subcritical, critical, or supercritical mass of uranium?
4. Make a "fence" form the sides of a cardboard box, 0.5 to 1 m high. Reset the mousetraps. Put the two corks on each trap as before. Then put the fence around the entire arrangement. Before you toss in a cork, write what effect you think the fence will have on the number of traps that spring. Explain. Then toss in a cork (repeat until a least one trap springs).



5. a. How many traps snapped? How close was your guess?
   b. What percentage of 32 mousetraps is this?
6. Now remove every other mousetrap in checkerboard fashion and reset the remaining 10 traps with 2 corks each. Place the "fence" around them. If you toss in a cork, what effect will removing every other mousetrap have on the percentage of traps that spring? Give a reason.
7. How many mousetraps sprang? What percentage of 16 mousetraps is this? How close was your guess?
8. Regroup the 16 mousetraps in a closely-spaced array. Reset the corks and place the "fence" around the set-up. Toss in the cork. How many mousetraps sprang? What percentage of the total is this?
9. Compare your answers to 8 and 5b. What does this comparison tell you about the relationship between the *number* of mousetraps and the percentage that spring?
10. Compare your answers to questions 8 and 7. What is the effect of *spacing* between mousetraps on the percentage that spring?

OPTIONAL

Investigate the effect of suspending strips of flypaper above the array of mousetraps. What do you think will happen? What functions as the flypaper in a nuclear reactor?

Student Handout 3–6

Nuclear Reactions Worksheet

1. Find the missing product in the first nuclear reaction ever observed (by Rutherford):

   $^{4}_{2}\mathrm{He} + {}^{14}_{7}\mathrm{N} \to ? + {}^{1}_{1}\mathrm{M}$

2. Find the missing product that was discovered by James Chadwick in the following reaction in 1932:

   $^{4}_{2}\mathrm{He} + {}^{9}_{4}\mathrm{Be} \to {}^{12}_{6}\mathrm{C} + ?$

3. Find the daughter nucleus when $^{239}_{94}\mathrm{Pu}$ undergoes alpha decay.

   $^{239}_{94}\mathrm{Pu} \to {}^{4}_{2}\mathrm{He} + ?$

4. What isotope is formed when $^{232}_{92}\mathrm{Th}$ absorbs a neutron?

   $^{1}_{0}\mathrm{n} + {}^{232}_{90}\mathrm{Th} \to ?$

5. Student Handout 3–2, "The Basics of Nuclear Fission," shows the "breeding" of $^{238}_{92}\mathrm{U}$ into $^{239}_{94}\mathrm{Pu}$ by two beta decays. After $^{232}_{90}\mathrm{Th}$ absorbs a neutron (as in question 4), two beta decays result in another fissionable isotope of uranium, $^{233}_{92}\mathrm{U}$. Write the equations for the "breeding" of $^{232}_{90}\mathrm{Th}$ into $^{233}_{92}\mathrm{U}$.

6. In the fission of $^{235}_{92}\mathrm{U}$ observed by Hahn and Strassman, one of the fission fragments (or fission products) was an isotope of barium. Suppose it was $^{142}_{56}\mathrm{Ba}$. If two neutrons are also emitted, what is the other fission fragment?

   $^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \to 2\,{}^{1}_{0}\mathrm{n} + {}^{142}_{56}\mathrm{Ba} + ?$

7. $^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \to ? + {}^{1}_{0}\mathrm{n}$

8. Complete the following equations, and identify the kind of radioactive decay that occurs in each.

   a. $^{14}_{6}\mathrm{C} \to {}^{14}_{7}\mathrm{N} + ?$

   b. $^{232}_{90}\mathrm{Th} \to {}^{228}_{88}\mathrm{Ra} + ?$

   c. $^{3}_{1}\mathrm{H} \to {}^{3}_{2}\mathrm{He} + ?$

   d. $^{133}_{56}\mathrm{Ba}^{*}$ (excited state of $^{133}_{56}\mathrm{Ba}$) $\to {}^{133}_{56}\mathrm{Ba} + ?$

   e. $^{212}_{84}\mathrm{Po} \to {}^{208}_{82}\mathrm{Pb} + ?$

   f. $^{90}_{38}\mathrm{Sr} \to {}^{90}_{39}\mathrm{Y} + ?$

Student Handout 3–7

Radioactivity Game

In many cases the daughter nucleus of a radioactive decay process is itself radioactive. This is always true if the atomic number of the daughter nucleus (or any nucleus) is greater than 83. (These nuclei are often called *heavy nuclei.*) The sequence of radioactive decay processes exhibited by heavy nuclei is often called a *radioactive decay chain.* There are four such chains, terminating with the stable isotopes $^{206}_{82}\mathrm{Pb}$, $^{207}_{82}\mathrm{Pb}$, $^{208}_{82}\mathrm{Pb}$, and $^{209}_{83}\mathrm{Bi}$, respectively. You can become familiar with these radioactive decay chains by playing the following game.

To begin the game, each player places his/her marking token on the square representing one of the starting nuclei: $^{240}_{94}\mathrm{Pu}$, $^{237}_{93}\mathrm{Np}$, $^{241}_{95}\mathrm{Am}$, $^{238}_{92}\mathrm{U}$, $^{242}_{96}\mathrm{Cm}$, $^{243}_{96}\mathrm{Cm}$, or $^{239}_{92}\mathrm{U}$. There is no limit to the number of tokens on each starting square and no limit to the total number of players.

Rules of Play: Each player takes a turn, in order, as follows: Throw the die. If a 1 or 2 is thrown, there is no radioactive decay, and the turn is over. If a 3, 4, or 5 is thrown, beta decay will occur for nuclei known to undergo it, and the marking token is moved to the daughter nucleus. If a 6 is thrown, alpha decay will occur for nuclei known to undergo it, and the marking token is moved to the daughter nucleus. A player's turn continues as long as radioactive decay continues to occur.

Winning the Game: The player whose nucleus decays to the end of its respective radioactive decay chain first is the winner.

Lesson 4
Energy Resources and Technologies

In the study of energy options, it is important that students become familiar with today's energy resources and the technologies that convert them for human use. This lesson gives students an overview of the capabilities of both conventional and alternative energy technologies.

OBJECTIVES

Students should be able to:

- Demonstrate an understanding of the information about energy sources, conversion technologies, capabilities, resource constraints, and environmental impacts.
- Classify energy resources and technologies as centralized/decentralized, renewable/nonrenewable, and according to source "family."
- Perform some calculations using information about particular energy sources.

TARGET AUDIENCE

Students of Physics, Physical Science

TIME ALLOTMENT

Two to three class periods

MATERIALS

Student Handout 4-1, "Energy Resources and Technologies"
Student Handout 4-2, "The Generation of Electricity"
Information Sheets (16)

TEACHING STRATEGIES

Begin by asking students to brainstorm energy resources. Write all responses on the board. After a few minutes, ask students to critique the list, deleting incorrect responses and combining those that overlap. Then have students tell or guess the degree to which each source is currently used to meet U.S. energy needs, and the degree to which it could be used in the future.

After the discussion, either distribute the Information Sheets among class members and answer questions on Student Handout 4-1 as a class; or distribute the Information Sheets and Student Handout 4-1 to each student. Have them read the Information Sheets and answer the questions.

Answers to Student Handout 4–1

Fossil sources: oil, coal, natural gas.

Solar sources: solar photovoltiac, solar thermal conversion, active solar heating and cooling, passive solar heating and cooling, ocean thermal energy conversion, wind power, bioconversion of plants and organic wastes, hydroelectric.

Nuclear sources: uranium, thorium, plutonium in conventional and breeder reactors, deuterium in fusion reactors.

Geothermal sources: geothermal conversion.

1. They are composed of the remains of once-living organisms that have been preserved in the earth's crust and transformed geologically.
2. Direct: solar photovoltaic, solar thermal, active solar heating and cooling, passive solar heating.

Indirect: Ocean thermal, wind, bioconversion of plants, bioconversion of organic wastes, hydroelectric.

3. Sunlight must be present for the direct sources to operate. The indirect sources utilize solar energy stored in plants, wind, and water.
4. All three technologies produce energy from a nuclear reaction.

5. **Energy Source**	**Centralized**	**Decentralized**	**Both**
Oil	x		
Coal	x		
Natural Gas	x		
Bioconversion of plants			x
Bioconversion of organic wastes			x
Solar photovoltaic conversion		x	
Solar thermal conversion	x		
Ocean thermal conversion	x		
Active solar heating and cooling		x	
Passive solar heating		x	
Wind power generation			x
Hydroelectric conversion			x
Conventional fission reactors	x		
Breeder fission reactors	x		
Nuclear fusion reactors	x		
Geothermal conversion			x

6. Oil—supply is critical.
Coal—severe environmental impacts.
Natural gas—supply is critical.
Active solar heating—availability of sunlight.
Passive solar heating—availability of sunlight.
Hydroelectric—little expansion anticipated.
Conventional fission—supply of fuel is limited.
Geothermal conversion—limited geographically.

7. Technology

Energy Source	Centralized	Decentralized	Resource Constraint
Bioconversion of Plants	Unproven	Proven	Space for Growing
Bioconversion of Organic Wastes	Unproven	Proven	None
Wind Power	Proven	Proven	Critical wind speeds
Hydroelectric	Proven	Proven	Most large sites have been developed
Geothermal	Proven	Proven	Available in limited areas

8. Oil and natural gas are in very short supply; coal is environmentally harmful. Nuclear technology could provide electricity for about 2,000 years if the breeder is used, or virtually forever if fusion becomes practical, provided other problems are overcome.
9. Answers will vary. If students say more, they should address questions of supply and implementation. If students say less, they should address the problems of supply and safety.

Answers to Student Handout 4–2

1. 11 percent.
2. No. Most large hydroelectric sites have been developed.
3. Oil, coal, natural gas, uranium, geothermal, solar thermal
4. Photovoltaic, OTEC, bioconversion, wind, geothermal.
5. Answers will vary, but should note the difference between distribution and transmission from a central source and decentralized generation that will not need such an elaborate system.
6. Oil. There is a limited supply of oil, and most of it is produced in other countries.
7. It imports oil from other countries.
8. Bioconversion of plants and organic wastes, gasification and liquefaction of coal.
9. 1.90×10^{16} Btu ÷ 7500 Btu/16 biomass = 2.53×10^{12} lbs
   2.53×10^{12} lbs ÷ 2000 lbs/ton = 1.27×10^{9} tons
   1.27×10^{9} tons ÷ 20 tons/acre biomass = 6.35×10^{7} acres
   6.35×10^{7} acres ÷ 0.50 efficiency = 12.7×10^{7} acres
10. 12.7×10^{7} acres ÷ 640 acres/sq. mi. = 1.98×10^{5} sq. mi.
11. Yes. The land would have to be taken from existing farmland in some cases. Other problems include water requirements, soil nutrients, climatic factors.
12. This would reduce the land requirement to less than one-third of the answer to question 10 (or 65,340 sq. mi.)

Information Sheet 1
Petroleum

Production and Conversion: Oil, the fossil remains of ancient organic material, is trapped within the earth in several forms and may be recovered by drilling, pumping, and in some cases, mining. The crude product then can be refined to produce high energy liquid fuels such as gasoline, diesel oil, fuel oil, kerosene, and others.

Energy Supply Capabilities: Oil products are highly flexible and transportable. Oil powers transportation and can be burned to provide heat, light, and electricity. Other important, non-energy uses include petroleum chemical feedstocks and lubricating oils.

Resource Constraints: Our dependence on oil, especially for transportation but also in every sector of society, is much higher than remaining supplies can support for long. In the U.S. and much of the western world, oil imports are essential to oil consumption rates and patterns. Much imported oil comes from countries that are not politically sympathetic to the West. Therefore, supply disruptions and price instability make oil an unreliable source.

Environmental Impact: Moderate air pollution; low water pollution; moderate land use impact.

Information Sheet 2
Coal

Production and Conversion: Coal, composed of the remains of once-living plants, is found in seams beneath the surface of the earth and is produced by underground or strip mining. Coal can be burned to release large amounts of heat. It can also be converted to gaseous and liquid fuels.

Energy Supply Capabilities: As a solid, coal can be burned to produce heat and electricity either in centralized power stations or locally. Coal can be converted to liquids, replacing oil for transportation and feedstocks, or to gases, for industrial and personal energy needs.

Resource Constraints: Although coal is nonrenewable, the resource base is very large. The constraining factors fall into other categories: severe pollution problems, high occupational risks, negative social impacts.

Environmental Impact: High air pollution (suifur, particulates, acid rain); moderate water pollution (acid mine drainage, thermal pollution); high land use impact (mining, transportation).

Information Sheet 3
Natural Gas

Production and Conversion: Natural gas, formed by the same processes that formed oil and coal, exists primarily as methane, and in small amounts as propane and butane. Natural gas is often found with oil and can be extracted at those sites. Because of its mobility, it can be located, drilled, and collected separately from gas wells.

Energy Supply Capabilities: Natural gas is a highly flexible fuel that provides heat and electricity. It is especially important for some manufacturing needs, residential and commercial cooking, and in liquid state, as fuel in isolated areas.

Resource Constraints: Demand for natural gas is much higher than remaining supplies can sustain for long. World supplies will be exhausted in less than 150 years at present consumption rates. Because of price differentials and pricing policies, supply interruptions also have been a problem in the past.

Environmental Impact: Low air pollution; low water pollution; moderate land use impact.

Information Sheet 4
Biomass (Plants)

Production and Conversion: Radiant energy from the sun is converted into chemical energy in vegetation by photosynthesis. Biomass, a term that includes all kinds of plant material, can be grown, harvested, and burned as a fuel.

Energy Supply Capabilities: Biomass has about one-half the energy content per unit mass of the high energy coals. Biomass can be burned to produce energy for heating and electrical generation. It also can yield liquids that can be combined with gasoline as fuel for transportation.

Resource Constraints: Land for growing enough plants to produce large amounts of energy is limited. Biomass crops often compete indirectly with food crops for growing space. Large plantings of single species crops (monocultures) are particularly susceptible to epidemics and insect infestations.

Environmental Impact: Low air pollution; low water pollution; moderate land use impact.

Information Sheet 5
Biomass (Organic Waste)

Production and Conversion: Urban waste, municipal sewage sludge, industrial waste, and agricultural and forestry residues can be used for fuel. The organic components of waste can be burned as fuel, or the waste can be biologically converted to liquid and gaseous fuels.

Energy Supply Capabilities: Organic waste can be burned to produce electricity in large, central generating stations. Thermal and biological processes can produce liquids and gases for heating, electricity, industrial uses, etc.

Resource Constraints: Converting organic waste to fuel is economically attractive because it makes efficient use of often "valueless" material and because landfill sites are costly and often scarce. Recycling glass, metal, and other valuable products also increases the attractiveness of organic waste conversion. Manure and crop residues may be more useful as fertilizers and soil builders.

Environmental Impact: Low air pollution; low water pollution; low land use impact.

Information Sheet 6
Photovoltaics

Production and Conversion: Radiant energy from the sun can be directly converted to electricity by the photovoltaic effect of solar cells. The movement of electrons in a wafer of silicon makes an electric current. Large arrays or panels of these cells have been used in remote areas of the world and to power spacecraft. However, the installation of photovoltaic arrays for commercial, residential, and industrial use is increasing rapidly.

Energy Supply Capabilities: Electricity produced by photovoltaics is as useful as electricity from any other source. In some cases it may be more economical because peak availability of sunlight coincides with peak hours of the summer cooling load.

Resource Constraints: The availability of sunlight is the most important supply factor. Weather and tall buildings can both interrupt the supply factor. Storage can be a problem, although most small installations sell extra power to a local utility, thereby using the utility grid itself as storage.

Environmental Impact: Low air pollution; low water pollution; moderate land use impact.

Information Sheet 7
Solar Thermal Conversion

Production and Conversion: Radiant energy from the sun can be converted to high quality electricity either by focusing large arrays of mirrors (heliostats) on a central tower (receiver) or by collecting the heat at distributed receivers and transmitting it to a power plant.

Energy Supply Capabilities: In the central receiver system (the power tower), solar energy can be concentrated by a factor as high as 1000 times to produce supersaturated steam at 482°C to 538°C. This steam is used in turbines to generate electricity. Distributed receiver systems do not produce temperatures in this range, but they can operate on indirect sunlight. In both cases, electricity is produced, and peak power output should coincide roughly with peak demand.

Resource Constraints: The central receiver system requires full sunlight, but the distributed receiver system can operate on indirect sunlight or in hazy conditions. The requisite temperature for a specific purpose will determine which system is most useful in a specific application.

Environmental Impact: Low air pollution; low water pollution; moderate land use impact.

Information Sheet 8
Ocean Thermal Energy Conversion (OTEC)

Production and Conversion: Radiant energy from the sun is stored in the earth's oceans. This solar energy can be used to operate a heat engine. For example, a working fluid such as ammonia can be evaporated using the heat of the warm surface water. The ammonia steam would be used to produce electrical power. The gaseous ammonia then would be cooled by low temperature water from the ocean depths and would be converted back to a liquid for the next cycle of the heat engine.

Energy Supply Capabilities: OTEC does not depend directly on availability of sunlight—solar energy is already stored in the oceans. OTEC electricity could be transmitted to shore or could be used at the site of generation for energy-intensive manufacturing (for example, aluminum refining).

Energy Supply Capabilities: Resource constraints in OTEC technology are almost nonexistent: the energy resources are huge and constantly renewed. However, the geographical constraints of site location, saltwater corrosion, plant growth, and the threat of hurricanes and ocean storms limit the technology for producing ocean energy.

Resource Constraints: Low air pollution; moderate water pollution; low land use impact.

Information Sheet 9
Active Solar Heating and Cooling

Production and Conversion: Solar energy is harvested by flat plate collectors arrayed on rooftops or near buildings. The heat energy is carried by a medium such as water or air to the point of use or into storage.

Energy Supply Capabilities: Active solar heating systems can easily supply most of the energy needed for a home's space heat and hot water. Solar cooling requires higher temperatures, but with the addition of concentrators or in combination with a heat pump, active solar cooling systems are feasible.

Resource Constraints: Weather and tall buildings can block local access to the solar resource, but adequate solar energy is available in most of the U.S. for home heating and cooling.

Environmental Impact: Low air pollution; low water pollution; low land use impact.

Information Sheet 10
Passive Solar Heating

Production and Conversion: In a passive solar heating system, sunlight is admitted through a window or similar device and stored in some form of mass (such as water, concrete, brick, or stone) and then reradiated as heat.

Energy Supply Capabilities: Passive solar can be used for space and water heating. It can also cool buildings by ventilation and evaporation devices. Passive solar heating systems are used only in buildings, and for the most part in new buildings. Because of the special design features that must be used to collect the solar energy, these buildings are highly self-sufficient.

Resource Constraints: The availability of solar energy—dependent on weather and surrounding buildings—is the only resource constraint. Technologically, passive solar is most easily and economically incorporated into new buildings because of the necessary siting and design features. However, retrofits are often possible and economical.

Environmental Impact: Low air pollution; low water pollution; low land use impact.

Information Sheet 11
Windpower

Production and Conversion: Wind energy is a form of solar energy that results from uneven heating of the earth's surface. The energy reradiated from the surface causes great masses of air to move, making wind. Local wind patterns result from topography and weather as well as from global winds. Wind-generated electricity is the major new use of an old technology, windmills. Both large, centralized systems using networks of wind turbine generators, and small, decentralized applications for homes and small businesses are being pursued.

Energy Supply Capabilities: Large, centralized, wind-driven electrical generation systems produce electricity. Small scale, decentralized wind systems can be used for electrical generation, battery storage, and a wide variety of mechanical applications such as pumping water, grinding, and compressing gases and liquids.

Resource Constraints: Most wind generation systems are limited by the availability of energy-producing wind speeds. Winds travelling from 8 to 60 miles per hour and faster can be tapped, but greatest efficiency is gained from constant, moderate winds. Unless the centralized electric power grid is used, storage and transmission of the electricity can be difficult.

Environmental Impact: Low air pollution; low water pollution; moderate land use impact.

Information Sheet 12
Hydroelectric Conversion

Production and Conversion: Flowing water is currently used to generate electrical power and in some instances in direct mechanical applications such as grinding grain. The technology is an old and proven one based upon the hydrologic cycle which is driven by the sun. Water evaporates from the earth's surface and redistributes through precipitation. The water flowing from higher elevations can be used to turn turbines and water wheels as it flows down to sea level.
Energy Supply Capabilities: Hydropower currently produces about 11 percent of this country's electricity. Most of the supply is generated in large, centralized sites and distributed through traditional transmission networks. New research and development efforts cover small, decentralized, low-water-flow systems for local community applications.
Resource Constraints: Most suitable sites for large scale electric generation are now in use. The lack of suitable sites, transmission losses, and environmental protection will limit further development of massive hydropower installations like the Hoover Dam. Efforts to use new low pressure turbines in small, decentralized applications may allow us to derive more electrical and mechanical energy from flowing water sources. As is true of all solar sources, hydropower sites are affected by the weather—in this case, by drought.
Environmental Impact: Low air pollution; moderate water pollution (flow change); high land use impact (flooding, ecosystem effects).

Information Sheet 13
Conventional Fission Reactors

Production and Conversion: Uranium ore is mined, concentrated, and refined to produce an enriched uranium that is used as fuel in a nuclear power plant. There, a controlled nuclear fission reaction releases large amounts of heat that produce steam to drive turbines and generate electricity.
Energy Supply Capabilities: Conventional reactors are used to generate electricity in much the same manner as large, centralized fossil fuel powered systems. The electricity generated can be used in exactly the same way and with the same efficiency as electricity generated by existing fossil fuel systems.
Resource Constraints: Uranium ore supplies in the U.S. are fairly large, but not unlimited. Eventually, these supplies will be depleted. Constraints fall into other categories: radioactive waste disposal, public concern over health and safety, poor economic performance.
Environmental Impact: Low air pollution; medium water pollution (thermal pollution); medium (mining) to high (waste storage) land use impact.

Information Sheet 14
Breeder Fission Reactors

Production and Conversion: Breeder reactors are similar to conventional reactors with two notable exceptions: they can use a more commonly occurring isotope of uranium; and they can produce more fuel than they use in the fission process. Therefore, breeders can produce not only high energy steam, but also enough fuel to power a second reactor (after 8 to 21 years of operation).
Energy Supply Capabilities: Breeder reactors generate electricity and could be hooked into the centralized transmission and distribution system in the same manner as fossil fuel plants and conventional nuclear reactors. The electricity generated can be used for the same ends and with the same efficiency as currently existing systems.
Resource Constraints: Breeder reactors are fueled by a nonrenewable resource. Although they generate more fuel, eventually fuel supplies will be depleted. The generation of plutonium 239 in the breeder reactor cycle presents a unique resource constraint. This new man-made element, a prime reactor fuel, is also the basic ingredient of a nuclear bomb. Its creation and transportation usher in a new set of resource constraints which are largely social in nature.
Environmental Impact: Low air pollution; low water pollution; medium (mining) and high (waste storage) land use impact.

Information Sheet 15
Nuclear Fusion Reactors

Production and Conversion: When two light nuclei combine or fuse to form a heavier nucleus, energy is released. This simple fact describes the process of nuclear fusion which promises huge amounts of energy from very small amounts of fuel. Sustaining the tremendous temperatures, pressures, and densities required for the fusion reaction to take place and producing more power than is needed to activate the process are two technical challenges that have not been met.

Energy Supply Capabilities: Fusion reactors will generate electricity in a traditional, centralized system.

Resource Constraints: While fusion reactors would use naturally occurring elements that are not renewable, very small masses of fuel would produce great amounts of energy. Each ton of deuterium could produce 10 million times more energy than a ton of coal. Therefore, deuterium from the oceans could be used to generate high quality energy for millions of years.

Environmental Impact: Low air pollution; low water pollution; low land use. Waste disposal impacts are unknown at this time.

Information Sheet 16
Geothermal Energy

Production and Conversion: Geothermal energy is the product of energy released by the radioactive decay of elements in the earth's core. Heat from this decay is conducted through the earth's crust. This heat is concentrated in hot spots near the edges of the continental plates. Where water is present as well, the heat—as steam or boiling water—can be tapped for electric generation and heating.

Energy Supply Capabilities: Steam and boiling water heated by geothermal energy can be used for heating, cooling, and electrical power generation. The quality of energy produced varies with the source. If a site produces high energy steam, then it can be coupled with a turbine to generate electricity. If a site produces hot water, it can be used for heating and cooling.

Resource Constraints: Geothermal resources are limited by geography. The majority of domestic sources seem to be located in the mountain and western states; a few sites are scattered over the rest of the U.S. Although these resources are site-specific, groundwater replenishment and the long term supply of heat from the earth's core guarantee a long-lived supply.

Environmental Impact: Moderate air pollution; moderate water pollution; moderate land use impact.

Student Handout 4-1
Energy Resources and Technologies

Sixteen energy resources and technologies which have varying capabilities to produce energy for electricity, heating and cooling, transportation, and other personal and societal needs have been identified and listed in the "Energy Resources and Technologies Information Sheets."

The sources and technologies listed in the information sheets may be classified in several ways. First, group them under these headings: fossil sources; solar sources; nuclear sources; geothermal sources. Then answer the questions that follow.

1. Why are oil, coal, and natural gas called fossil fuels?
2. The solar sources form a large energy source "family." Some of these sources produce energy directly from sunlight while others offer solar energy indirectly. Classify the solar sources as direct or indirect. Include the various conversion technologies in your list.
3. What is the basic difference between these two solar groups?
4. What do the nuclear sources have in common?
5. The following definitions will help you to classify all these energy resources in a different way. Study each resource and decide whether it can be used in centralized applications, decentralized applications or both.

Centralized Energy Technologies: These are large-scale technologies. The energy is converted in one location and distributed to users in a number of ways. These technologies produce large amounts of energy which are then distributed to large numbers of users.

Decentralized Energy Technologies: These are medium and small-scale technologies. Energy sources and uses are mostly local and renewable.

Energy Source	**Centralized**	**Decentralized**	**Both**
Oil	___	___	___
Coal	___	___	___
Natural Gas	___	___	___
Bioconversion of plants	___	___	___
Bioconversion of organic wastes	___	___	___
Solar photovoltaic conversion	___	___	___
Solar thermal conversion	___	___	___
Ocean thermal conversion	___	___	___
Active solar heating and cooling	___	___	___
Passive solar heating	___	___	___
Wind power generation	___	___	___
Hydroelectric conversion	___	___	___
Conventional fission reactors	___	___	___
Breeder fission reactors	___	___	___
Nuclear fusion reactors	___	___	___
Geothermal conversion	___	___	___

6. Several of these energy resources are in wide use today. List them and tell the resource constraints for each.
7. Certain technologies can be used in both centralized and decentralized applications. Tell whether these technologies are proven or unproven in both categories. List any constraining factors.
8. What is the long-term outlook for the fossil fuel energy resources and the nuclear sources in large-scale, centralized electricity production?
9. Do you think we will use more or less decentralized energy technologies in the future? Explain.

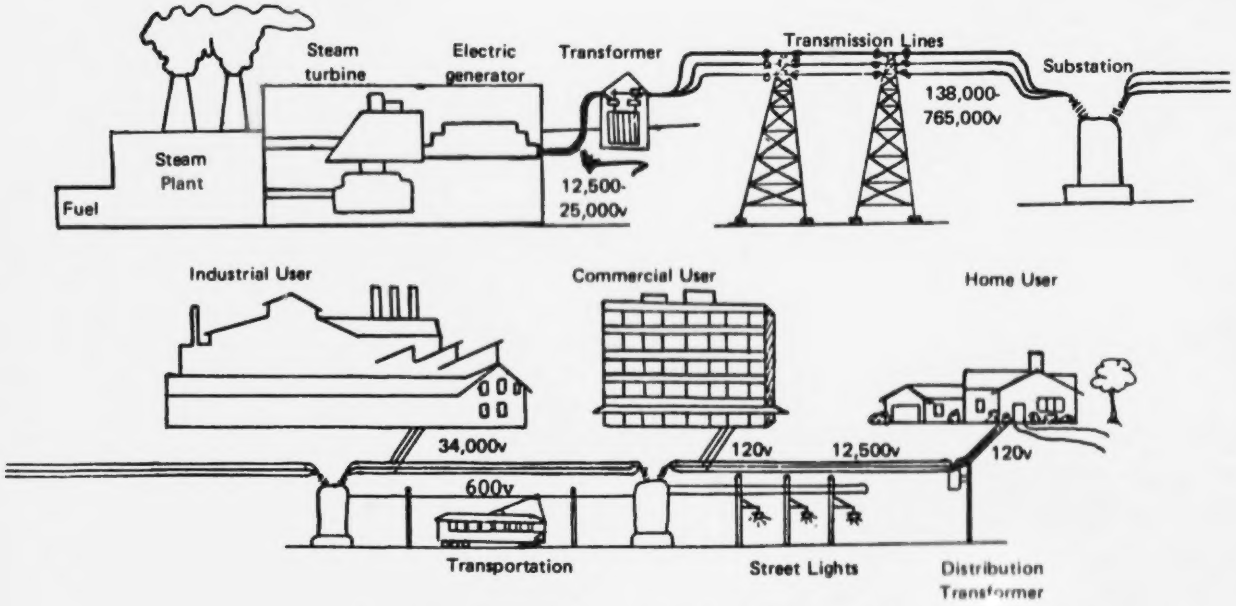
Student Handout 4–2
The Generation of Electricity

Electric energy is the kinetic energy that is obtained when electric charges are set in motion by electrical forces, just as mechanical kinetic energy is obtained when mass is set in motion.

To be used, electricity must be generated, transmitted, and distributed. Currently, most generation of electricity is accomplished by two sources of mechanical energy: falling water turning a turbine in a direct hydroelectric conversion process, and heat engines, mostly turbines driven by steam.

Study the diagram below, which shows the generation, transmission, and distribution phases of electricity, and use the Information Sheets to answer the following questions.

1. What percent of electricity is generated by the hydroelectric process?
2. Is it possible to increase this portion of the total by any appreciable amount? Why?
3. Steam power plants require high temperature steam to turn steam turbines. What energy sources are currently capable of producing energy of this quality for industrial and commercial use?
4. In the future, electrical generation from fossil fuels, nuclear, and hydro may not provide us with the energy we need. List other sources that might be used for generating electricity.
5. Using the information sheets, describe the electrical generation, transmission, and distribution system in the twenty-first century if it were fueled by alternate energy sources.
6. What primary energy source provides most of the energy for transportation? What are the constraints on that source?


Steam turbine
Electric generator
Transformer
Transmission Lines
Substation
138,000-765,000v
Steam Plant
Fuel
12,500-25,000v
Industrial User
Commercial User
Home User
34,000v
120v
12,500v
120v
600v
Transportation
Street Lights
Distribution Transformer

Generation, Transmission, and Distribution of Electricity

7. How is the United States able to consume more of this energy source than it produces?
8. What alternative energy technologies are capable of producing liquid and gaseous fuels for transportation?
9. Use the data below to calculate how many acres of biomass would have had to be grown to support the fuel requirements of the transportation sector in 1983.

   Facts:

   a. In 1983 the transportation sector consumed approximately 1.90×10^{16} Btu.

   b. Plant biomass contains approximately 7500 Btu per pound.

   c. The average yield of a biomass crop is 20 tons per acre.

   d. Assume that biomass can be converted with 50 percent efficiency.
10. Approximately how many square miles does this represent (1 square mile = 640 acres)?
11. Do you see any problem with converting this amount of land to energy crops?
12. The current car and light truck passenger fleet has an average fuel economy of about 15 miles per gallon. If they were improved to about 50 miles per gallon, how would this change the amount of land needed to produce liquid fuels for the nation?

Lesson 5

Biomass Conversion Processes

This lesson gives students information on the processes used for handling organic wastes: the conversions to fuel of agricultural and forestry residues, and municipal and industrial wastes. It summarizes some basics of organic chemistry, including the components of food produced by plants: sugar, starch, and cellulose. Activity 1 summarizes biomass conversion processes. Activity 2 demonstrates the fermentation and distillation of ethanol (grain alcohol). Activity 3 allows students to follow the transformation of sugar, starch, and cellulose to the end product—ethanol—an energy source. Activity 4 investigates the pyrolysis of wood splints to produce both a gas and distillation products. Activity 5 demonstrates the energy content of gasoline, methanol and ethanol. In Activity 6, students determine the needs and prospects for bioconversion in their community and find out what techniques are currently used. This is an ongoing activity that will require time for completion outside of class.

OBJECTIVES

Students should be able to:

- Briefly list and describe seven to ten conversion processes for biomass.
- Describe the steps in the conversion of sugar to ethanol by yeast and the isolation of ethanol through distillation.
- Describe the methods of producing ethanol from sugar, starch, and cellulose.
- Describe (or perform) a method of converting wood to methane, methanol, and charcoal.
- Record and compare the performance of a gasoline engine's operation using regular gasoline and using a 10 percent alcohol-gasoline mixture.
- Describe the generation and disposition of wastes at four industry or business offices in the community.

TARGET AUDIENCE

Students of Chemistry, Environmental Science, Biology

TIME ALLOTMENT

Four to six periods

MATERIALS

Student Handout 5-1, "Biomass Conversion Processes"
Student Handout 5-2, "Fermentation and Distillation of Ethanol"
Student Handout 5-3, "Biomass Flow for Ethanol Production"
Student Handout 5-4, "Pyrolysis of Wood"
Student Handout 5-5, "Lawn Mower"
Student Handout 5-6, "Survey"

Activity 2
One cake of yeast (small) or package of activated dry yeast
Sucrose or other sugar
Unsulfured molasses
Cornstarch, cornmeal, or other starch
Test tubes
Cotton plugs
One 500-ml flask with a side delivery tube
One condenser tube
One collecting test tube in cool water bath
One thermometer 10°C–100°C
One Bunsen burner or hot plate
Clamps and stands, as needed

Activity 4
Test tube(s)
One one-hole rubber stopper
One glass L-shaped delivery tube
Wood splints
One beaker
Cool water (iced)
One Bunsen burner or several alcohol burners
Clamps and stands, as needed

Activity 5
Stopwatches
One gasoline lawn mower
Gasoline (1000 ml)
Methyl alcohol (100 ml)
One funnel
Water (for diluting flammable liquid if spilled)
One fire extinguisher

TEACHING STRATEGIES

Begin by asking students to name the most common bioconversion process (direct combustion). Point out that this lesson does not cover bioconversion of crops grown specifically for that purpose. This lesson presents the methods by which *wastes* are changed to fuel. In addition to the positive attributes of bioconversion in general—the resource is renewable and the products can replace oil—bioconversion of organic wastes makes valuable a commodity that currently has negative value (i.e., producers must *pay* for its disposal).

Activity 1

Distribute Student Handout 5-1, "Biomass Conversion Processes." Discuss each process listed there in some detail. Use pictures from magazines where available. Tell students to save these pages for reference throughout this lesson. (You may wish to present the terms in the glossary at this time as well.)

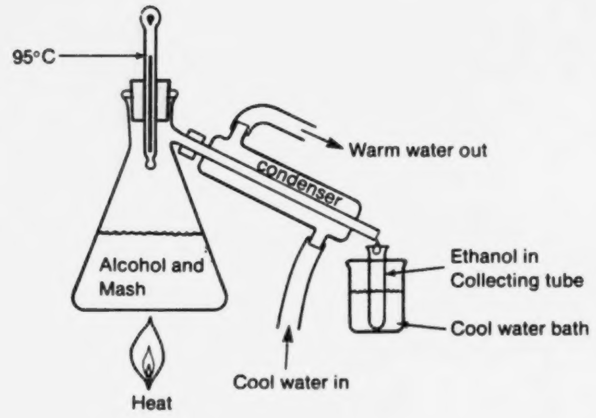
Activity 2

Present this activity as a demonstration to the class. It may be prepared and performed by several students under your supervision. Lead time of one to four days is needed for portions of this activity.

Start a yeast culture one day before this demonstration. Stir one-quarter of a cake of yeast into 200 ml of a solution of 10 percent molasses by volume. Pour it into a flask. Plug the mouth of the flask with cotton. Make a 10 percent solution by weight using cornstarch or other starch in water and add another quarter of the yeast cake. Pour it into another flask and plug it with cotton. Put both cultures in a warm place overnight. Examine each culture the next day for gas bubbles and the odor of alcohol. Remove a drop of each culture, add methylene blue, and look under a microscope for yeast cells with buds.

Make a 20 percent solution by weight of sucrose in 500 ml of water. Pour the mixture into a flask with a side delivery tube. Add another quarter of the yeast cake. (If a flask with side delivery tube is not available, a two-hole stopper may be used in the top of the flask: use one hole for a thermometer and one for a bent glass delivery tube.) Plug the top with cotton and put it in a warm place for several days until bubbling has essentially ceased.

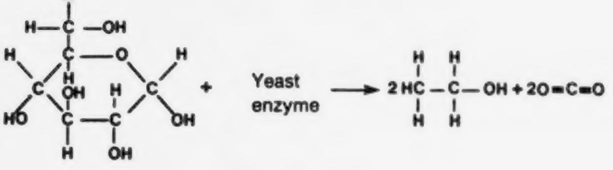
Distribute Student Handout 5-2, "Fermentation and Distillation of Ethanol." To separate the ethanol, arrange a distilling apparatus as shown.



Note: Alcohol vapors are highly flammable. Keep any flame away from the collecting test tube. To minimize vapors, use a water bath around the collecting tube.

The distillation will take approximately 20 minutes after the liquid reaches the boiling point. If the temperature at the neck of the flask rises above 95°C, stop collecting distillate. Test the distillate for odor. Pour a little on a clean flat metal surface or watch glass and ignite it. The ethanol flame is almost colorless. To show that the flame is burning, use it to ignite a paper. Ask students, "What does this indicate about the amount of noncombustible material in the ethanol?"

Place a few grains of sugar in a crucible and heat strongly until the sugar ignites. Describe the combustion of the sugar. On the chalkboard write the chemical equation for the fermentation of glucose sugar by yeast. (The structural formula will heighten the students' perception of the chemical energy bond reduction.)



Answers to Student Handout 5-2

1. Molasses and sugar.
2. To allow the generated CO_2 to escape.
3. Some yeast cells had buds on them; the solutions showed gas bubbles.
4. Liquid; gas (vapor); liquid.
5. So that the water would not vaporize also and mix with the ethanol again.
6. Odor: Like a cocktail or smell of bread baking.
7. Colorless and odorless.
8. Yellow, smoky; a strong odor of burning sugar.
9. Because sugar has a more complex structure than ethanol.
10. Sunlight.
11. Acid (for hydrolysis) or an enzyme to change starch to sugar.
12. Amylase in saliva and other enzymes.

Activity 3

Distribute Student Handout 5-3, "Biomass Flow for Ethanol Production." Use the flow chart to lead students through the various steps of this process. Then have them answer the questions either individually or as a class.

Answers to Student Handout 5-3

1. Cellulose. Students should reason that it takes two more steps than sugar and one more than starch to break down to the same type of molecule.

2. Starch. Hydrolysis is a process of decomposition involving the splitting of a bond and the addition of the elements of water.

3. In this process, cellulose does. Experiments are under way which may break down cellulose without the action of enzymes.

4. Sugar. However, point out to the students that this flow chart does not show the cost of producing the sugars, starches, and cellulose, which might change the economics involved.

5. Carbon dioxide, ethanol, and residues used for animal feed and distiller's grain called *slop*.

6. Distillation. This is a process of separating materials according to their different boiling points.

Activity 4

The pyrolysis of wood can be done as a student activity or as a demonstration. Pack a test tube tightly with wood splints; this will be the pyrolysis tube. Leave a space near the mouth of the tube so that splints are 1 cm or more below the stopper. Plug the mouth of the test tube with the one-hole stopper and delivery tube assembled. Mount the assembled test tube horizontally so that it can be heated strongly from several angles. Ready a beaker of cold water and another test tube to collect material from the pyrolysis tube.

Distribute Student Handout 5-4, "Pyrolysis of Wood." Heat the wood splints strongly. Observe the neck of the test tube as the splints become hot, and observe the emissions from the delivery tube. Position a test tube in a beaker of cold water to collect the vapors from the delivery tube. The cold water serves as the condenser. Continue heating the splints strongly until no more gas or liquid comes out. The splints should look thoroughly charred (10 or 20 minutes). Remove the condensing test tube, stopper it, and allow it to stand undisturbed overnight. Observe it at the end of heating and again the next day.

On the next day, carefully decant the top layer of liquid from the condensing tube and try to ignite each fraction of the liquid.

Empty the remainder of the splints from the pyrolysis tube. Try to burn one.

Answers to Student Handout 5-4

1. a. Cellulose has a longer chain structure.
   b. It is more complex than ethanol.
2. Drops of water.
3. Smoke; the gas burned.
4. To condense the vapor from the delivery tube.
5. Yes (homogeneous); no (two layers).
6. The top fraction burns.
7. Answers will vary. The fractions are methanol and tar.
8. They glow like charcoal.
9. Wood was heated strongly. A gas that burns was emitted. A liquid fuel was condensed. The wood changed to charcoal.

Activity 5

Do this activity as a demonstration. Use a small gasoline lawn mower (your school may have one, or a student may have one which can be lent to the class).

Note

Emphasize the dangers of this activity—*careless handling of gasoline may cause fire or explosion.*

Distribute Student Handout 5-5, "Lawn Mower." More than two students should keep time with stopwatches. The lawn mower will probably run 15 to 20 minutes. Run tests outside on a clean level surface; ethanol may be used in place of (or in a parallel experiment with) methanol. Have the students answer the questions in Handout 5-5.

Answers to Student Handout 5-5

1. Time will vary.
2. Time will vary, but it should be longer than the time in question 1.
3. The pure gasoline should run longer.
4. Pure gasoline has higher energy value.
5. Yes, methanol is being used in experiments.
6. Yes, if it is modified considerably.

Activity 6

Distribute Student Handout 5-6, "Survey." Discuss it with the students and assign it as either an individual or a group activity.

Individual Activity: Assign students specific types of biomass to study, such as municipal sewage and garbage, or specific locations, such as individual homes, businesses, or industrial sites.

Group Activity: Divide students into teams to survey the activities in their community. Give each member of each team a specific task assignment. Set a date for the completion of the survey, and check in with teams during the survey time period.

Check each student's answers to Handout 5-6. Answers will vary, depending on activities in your community, but should reflect students' research.

Students should attempt to get publicity for the results of their survey and recommendations. Radio stations and local newspapers will often cooperate.

Glossary

Aerobic digestion: Action of bacteria, in the presence of oxygen or air, that causes a chemical change in a material.

Anaerobic digestion: Action of bacteria on fecal material, in the absence of air, that changes it to a more inert form.

Bioconversion: A general term describing the change of one form of energy into another by plants or microorganisms.

Distillation: The process of separating a mixture of two materials that have different boiling points by controlled heating of the mixture.

Ethanol: Ethyl alcohol, CH_3CH_2OH.

Fermentation: The process by which yeast changes a sugar to ethanol and carbon dioxide.

Hydrolyze: To split a polysaccharide—like starch—into sugars by adding hydrogen to the oxygen bond that joins saccharide units.

Methanol: Methyl alcohol, CH_3OH.

Synthesis: Creation of a new, more complex material by joining simple materials together.

NOTES

1. C.R. Wilke, *Cellulose as a Chemical and Energy Resource* (New York: John Wiley and Sons, 1975).
2. C.G. Golueke, *Biological Reclamation of Solid Waste* (Emmaus, PA: Rodale Press, 1977).

SOURCES

P.S. Diamond and R.F. Denman. *Laboratory Techniques in Chemistry and Biochemistry*, John Wiley and Sons, New York, 1973.

J.M. Fowler. *The Energy-Environment Source Book*, National Science Teachers Association, Washington, DC, 1979.

J.M. Fowler. Factsheet #1, *Biofuels*, National Science Teachers Association, Washington, DC, 1977.

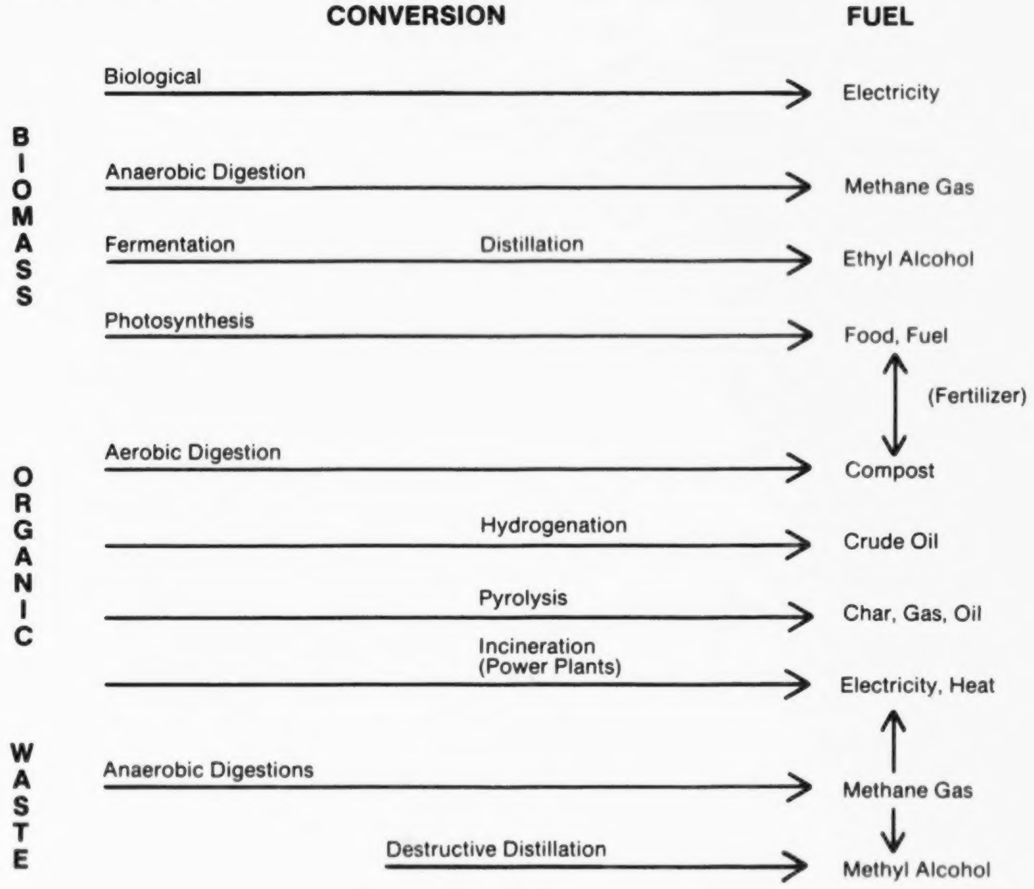
R.C. Loehr, ed. *Food, Fertilizer and Agricultural Residues*, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1977.

R. Merrill, et al. *Energy Primer*, Dell Publishing, Inc., Menlo Park, CA, 1978.

Proceedings: Conference on Capturing the Sun Through Bioconversion, The Bio Energy Council, Washington, DC, 1976.

"Solar Biomass Energy," *Science*, Vol. 199 (March 1978).

Low technology conversions


CONVERSION
FUEL
BIOMASS
Biological
Electricity
Anaerobic Digestion
Methane Gas
Fermentation
Distillation
Ethyl Alcohol
Photosynthesis
Food, Fuel
(Fertilizer)
ORGANIC
Aerobic Digestion
Compost
Hydrogenation
Crude Oil
Pyrolysis
Char, Gas, Oil
Incineration
(Power Plants)
Electricity, Heat
WASTE
Anaerobic Digestions
Methane Gas
Destructive Distillation
Methyl Alcohol

Student Handout 5-1

Biomass Conversion Processes

There are a variety of ways to convert plants directly into organic fuels, but impending food shortages suggest that alternative fuel production may not be the wisest use of land and crops. Organic wastes, on the other hand, are produced all around us. Although they are still generally considered a problem rather than a resource, there is little doubt that organic wastes will have to be used more and more as raw material for bioconversion and recycling. The potential importance of some of the conversion processes currently available is indicated in this quotation from a technical publication on cellulose as a chemical energy resource:

> Wood or other plant material was probably the first fuel. *Direct combustion* of organic matter remains our principal means of providing energy and is expected to continue so for at least several decades, regardless of technological breakthroughs, because of present resource investment in fossil fuel powered equipment.
>
> *Pyrolysis* was one of the first methods used to produce solid, liquid, and gaseous fuels and other useful by-products from wood, agricultural wastes, coal, and petroleum. Pyrolysis of urban refuse, of forest products, manure, and cellulose . . . shows that it is possible to vary the distribution between fuels and other products such as charcoal, activated carbon . . . methanol, synthetic gas, and other low molecular weight organic compounds.
>
> *Synthesis gas* (CO, H_2) has been produced from pyrolysis of many cellulosics, and is readily converted to ammonia (via H_2), (via CO), or pipeline gas (via hydrogasification). (1)

All of these processes either produce energy directly (for burning) or produce substitutes for fuels or petroleum products. For example, cellulose can be hydrolyzed (broken down) to glucose through acid and/or enzymatic hydrolysis. Cellulose-based materials, especially those rich in pentosans (glucose rings), such as oat hulls and corncobs, are converted to furfural (a chemical raw material used to make a variety of chemicals and polymers) by acid digestion. (2) Furan is made from furfural. It is the basis of nylon, which is one of the most widely used petroleum derivatives. But in this instance abundant plant material was substituted for scarce oil.

As a process, direct burning does not need discussion. The other most commonly used processes can be divided into two general categories, high technology and low technology.

High-technology conversions (requiring high temperatures, high pressures, or corrosive chemicals).

a. *Pyrolysis:* Organic wastes are heated (200°C–900°C) in the absence of air at atmospheric pressure to produce gas, oil, and char, all of which are combustible.

b. *Hydrogasification:* Organic wastes (especially manure) are gasified directly with hydrogen at high temperatures (500°C) and high pressures to produce substitute pipeline gases (methane, ethane).

c. *Hydrogenation:* Organic wastes are converted to oil by treatment with carbon monoxide and steam under pressure at high temperatures.

d. *Destructive Distillation:* High-cellulose organic wastes (wood and refuse) are heated, and the liquid residues are distilled to produce methyl alcohol.

e. *Acid Hydrolysis:* Wood wastes are treated with heat and acid to produce sugars for fermentation and distillation to ethyl alcohol.

Student Handout 5–2

Fermentation and Distillation of Ethanol

As you observe the process, record your answers to the following questions:

1. Which of the three yeast solutions showed signs of fermentation?
2. Why were the flasks plugged with cotton instead of being tightly stoppered?
3. Was there any evidence that the yeast cells grew in the sugar and molasses solution?
4. What is the physical state of ethanol as the solution enters the flask? At the neck of the flask and condenser? In the collecting tube?
5. Why was it important to keep the temperature of the vapor at the neck of the flask less than 100°C?
6. Describe the odor of ethanol.
7. What is the color and odor of the ethanol's flame?
8. What is the color and odor of the sugar's flame?
9. Why does it take more energy to ignite a small quantity of sugar than an equal quantity of ethanol?
10. What was the original source of energy used to form the sugar molecule?
11. Corn and other grains that are largely starch are fermented to make ethanol. What must be added to them in order to allow yeast to ferment them?
12. How does your digestive system change starch to sugar?

Student Handout 5–3

Biomass Flow for Ethanol Production

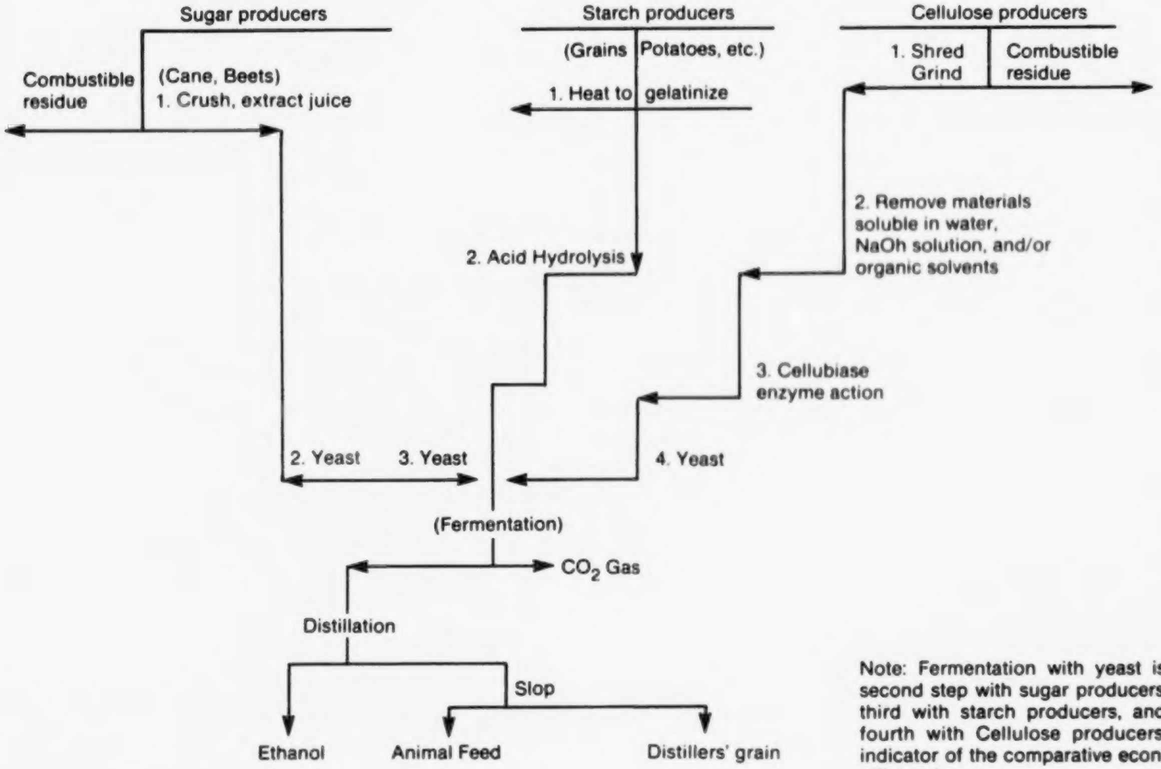
1. After you have studied the chart accompanying carefully, decide which contains the most complicated molecules—sugars, starches, or cellulose?
2. Which of the three carbohydrates must be treated with acid to hydrolyze the molecules? What is meant by hydrolysis?
3. Which carbohydrate requires an enzymatic action?
4. Which carbohydrate appears to be the most economically feasible?
5. What are the products of the fermentation of carbohydrates?
6. How is the alcohol (ethanol) recovered from the liquid remaining after fermentation?

Student Handout 5–4

Pyrolysis of Wood

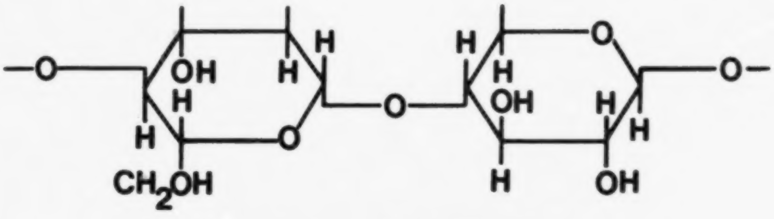
1. Refer to the molecular structure of wood (cellulose), of glucose, and of ethanol diagrammed above. How does the complexity of cellulose's structure compare to:
   a. Glucose?
   b. Ethanol?
2. What do you think the drops at the neck of the pyrolysis tube might be when the tube is first heated?
3. What evidence of decomposition is visible at the end of the delivery tube as heating proceeds?
4. What purpose does the ice water bath around the collecting test tube serve?
5. Does the liquid in the collecting tube look homogeneous at

Biomass Flow for Ethanol Production (Student Handout 5-3)

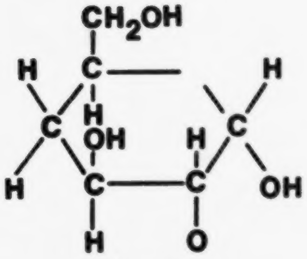

Sugar producers
Combustible residue
(Cane, Beets)
1. Crush, extract juice
2. Yeast
3. Yeast
Starch producers
(Grains Potatoes, etc.)
1. Heat to gelatinize
2. Acid Hydrolysis
Cellulose producers
1. Shred Grind
Combustible residue
2. Remove materials soluble in water, NaOh solution, and/or organic solvents
3. Cellubiase enzyme action
4. Yeast
(Fermentation)
CO2 Gas
Distillation
Slop
Ethanol
Animal Feed
Distillers' grain

Note: Fermentation with yeast is the second step with sugar producers, the third with starch producers, and the fourth with Cellulose producers—an indicator of the comparative economic efficiencies.

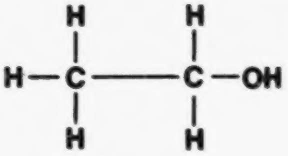
Pyrolysis of Wood



A portion of the polymer, cellulose (Note carbon atoms are located at the corner positions not occupied by oxygen.)



Glucose



Ethanol

the end of pyrolysis? After 24 hours?

6. Does either the top fraction or the bottom fraction of the liquid burn?
7. What do you think each part of the condensed liquid is?
8. Write a statement summarizing the pyrolysis of wood.

Student Handout 5–5

Lawn Mower

PROCEDURE

Measure 450 ml of gasoline. Put it into the empty gasoline tank of a mower. (BEWARE! Follow your teacher's instructions exactly. This must be done out-of-doors on a smooth, clean surface.) Measure 50 ml of methyl alcohol and add it to the tank of gasoline.

1. Now start your motor and run it continuously, timing it exactly. How long does it run?
   Rinse the tank with gasoline, then repeat the process, but use 500 ml of gasoline with nothing else added.
2. Now how long does it run?
   If you have good luck, with your motor running continuously until it runs out of gas each time, you should now have some comparison of the energy value of methanol versus gasoline.
3. Which trial ran the longest?
4. What does this tell you about the comparative energy values of methanol and gasoline?

OPTIONAL

Repeat the above investigation using a 10 percent ethanol mixture made the same way you made the methanol mixture. Answer the first three questions for your ethanol tests also.

5. Is methanol presently being used as a fuel additive? (Search the periodical files of your library and see if you can find any information on this subject.)
6. Can a conventional gasoline engine run on 100 percent methanol? On 100 percent ethanol?

Student Handout 5–6

Survey

Survey your area for those bioconversion activities that are in progress, those that are planned for the near future, or those that may need to be considered.

1. Is there an agricultural or industrial activity going on in your area that produces large biomass residues? (Think of feedlots, canneries, sawmills, furniture manufacturing, food products companies, government office buildings, printing companies, etc.)
2. What is currently being done with these wastes or residues?
3. What is being done with the municipal sewage and garbage from your area?
4. Are plans being made to improve the method now being used? If so, what? If not, has bioconversion been considered as a possible alternative?
5. Survey individuals that you know and ask what they do with their organic wastes (such as food products, leaves, grass clippings).
6. Estimate the cost-effectiveness of dumping versus recycling.

You may think of other important questions to ask.

From the results of this survey, make recommendations for future handling of the biomass in your area. Your completed report will consist of the answers to the six questions on this page and a summary of at least three additional reports by other individuals or groups. Use the format below for this summary.

SUMMARY

Name of Industry/Business:
Address:
Phone:
Type of Residue:

Use/Disposal of Residue:

Bioconversion Procedures in Use:

Recommendations:

Lesson 6

How Are Synfuels Produced From Coal?

It has been said many times that coal is the fuel that will carry the U.S. from the fossil fuel era of renewable resources. Part of this transitional fueling may be the conversion of coal to liquid and gaseous fuels. In this lesson students are exposed to the complexity of gasification and liquefaction techniques and their environmental impacts. Students demonstrate destructive distillation in the laboratory, then study the commercial counterpart of this gasification process. They compare four liquefaction processes, and survey the environmental effects of synfuels production.

OBJECTIVES

Students should be able to:

- Explain one laboratory method used to produce a flammable gas from coal.
- Describe and compare some of the industrial methods by which coal is converted into gaseous and liquid products.
- List some of the environmental impacts of coal conversion technologies.

TARGET AUDIENCE

Students of Chemistry

TIME ALLOTMENT

Five to six class periods

MATERIALS

Student Handout 6–1, "Gasifying Coal in the Laboratory"
Student Handout 6–2, "Gasifying Coal Commercially"
Student Handout 6–3, "Industrial Liquefaction of Coal"
Student Handout 6–4, "Environmental Effects of Producing Synfuels"

Activity 1 (for each group of 5–7 students)
Two 25 × 200 mm test tubes
One 1-hole stopper
One 2-hole stopper
Two glass tubes bent at 90° angle
One pail (one gallon)
One 250 ml beaker
One buret clamp
One mortar and pestle
20 g soft coal
One glass tube bent at 120° angle
One m rubber tubing
Three 250-ml gas collecting bottles
Three stoppers or glass plates for collecting bottles
pH paper
One wood splint
One Bunsen burner
One marking pencil or labels
Safety goggles
Glycerin

BACKGROUND INFORMATION

In this lesson, most of the background information can be found in the Student Handouts. In each of the activities there is some descriptive material about coal conversion technologies.

Activity 1

Because this activity includes a lab experiment, students will need two consecutive periods to complete the data collection. The results of the experiment depend on the quality of the coal; therefore, the teacher should try the experiment before presenting it to students. Soft coal produces the best results, and can be obtained from coal dealers. Most areas of the country have at least one local coal dealer. If necessary, write to the National Coal Association (1130 17th Street, NW, Washington, DC 20036).

Grind the coal to a fine powder using a mortar and pestle. If the coal seems to be particularly dirty (excess amounts of sulfur or rock), it may be necessary to clean the coal by placing it in a saturated solution of calcium chloride. The density of coal is lower than the $CaC1_2$ solution, allowing the coal to float on top while the heavier impurities sink. This could be done as a demonstration for students. (Do not, however, expect instant separation. The solution will probably have to be left for a few hours before the coal can be skimmed off the top.)

If you have a pH meter, you may want to monitor the pH of the water in the gas collection pail. If you have high sulfur coal, the pH should drop as SO_2 and SO_3 are bubbled through the water.

If students are familiar with the gas laws, you may want to have them convert the volume of gas collected over water to standard conditions (dry gas at 0° and one atmosphere pressure) before calculating the average molecular weight of the gas.

To begin this activity, distribute Student Handout 6–1, "Gasifying Coal in the Laboratory." Divide the class into small groups and have each group perform the experiment. After students have completed the experiment, they should fill in the Data Table, complete the calculations, and answer the questions.

Sample Data Table

1. Mass of test tube A empty: 31.28 g.
2. Mass of test tube A with coal: 49.83 g.
3. Mass of test tube B with tubing: 37.50 g.
4. Describe what is happening in test tube A while it is being heated. Gas (gray) is produced, moisture appears.
5. Describe the appearance of the glass tubing during heating. Tars collect.
6. Mass of test tube A after heating: 45.46 g.
7. Mass of test tube B with tubing after heating: 40.82 g.
8. What is the pH of test tube B? Variable, due to coal

variations.

9. Describe the substances (color, odor, etc.) that are left after heating in:
   Test tube A. Black solid; floats in water; dry.
   Test tube B. Yellow, tarry liquid.
   Gas in bottles. Colorless gas.
10. Total volume of gas collected: 485 ml.
11. What happens when the lighted splint is placed above the gas? Yellow flame.

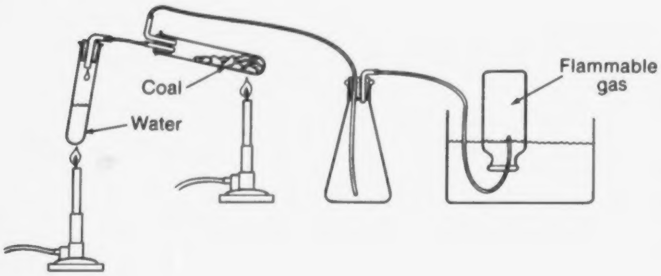
COMPLETED CALCULATIONS:
a . 18.55 g
b. 14.18 g
c. 3.32 g
d. 1.05 g. (18.55 - 14.18 - 3.32 = 1.05)
e. 76.4%; 17.9%; 5.7%.
f. 47.0 g/mole

Answers to Student Handout 6–1

1. Answers will vary.
2. CO, CO_2, C_2H_6.
3. No; only 5.7% of product is gas.
4. Air pollution; also cleanup is difficult.
5. Possibly; depends on the rate of formation of gas at the conclusion of the experiment.

Extending the Learning

You may want to try to produce a gas using a steam/heat mixture as shown below. This will show the reaction of steam and coal to produce carbon monoxide and hydrogen.



Another good demonstration is the burning of coal in air. Many students do not realize that it takes some time to get the coal to begin to burn.

Activity 2

The day before doing this activity in class, assign Part I of Student Handout 6–2, "Gasifying Coal Commercially," to students to read for homework. Then, in class, students can look at the diagram of the coal gasification process and answer the questions in Part II. When students have finished, go over the process as a class. (With some students, it may be necessary to go over the descriptions of the processes *before* they begin the questions.) Try to draw a correlation between the experiment in Activity 1 and the industrial process in this activity.

Answers to Student Handout 6–2

1. Coal.
2. Steam.
3. $C + H_2O \rightarrow CO + H_2$
4. $CO + H_2$
5. Unburned coal.
6. $CO + H_2 \rightarrow CO_2 + H_2$
7. CO_2 and H_2S
8. $CO + 3H_2 \rightarrow CH_4 + H_2$
9. Methane.
10. Unreacted CO, H_2, and H_2O vapor.

Extending the Learning

The process shown on the diagram is only one of the many processes being developed to convert coal into gas. Students could research other gasification processes and report to the class.

Activity 3

A demonstration of coal liquefaction would be a very effective teaching strategy; however, many of the process solvents are carcinogenic. Therefore, coal liquefaction is presented here in a reading and flow chart.

Use Student Handout 6–3, "Industrial Liquefaction of Coal,' either in class or as a homework assignment. Make sure students read the information carefully before beginning the questions. It may be best to review the questions in class using a transparency of the "Flow Chart of Liquefaction Techniques," included in Handout 6–3.

Answers to Students Handout 6–3

1. High temperature and pressure.
2. Pyrolysis.
3. Because liquid fuel is more important than gas. We use more oil than gas, we import about one-third of the amount we consume, and our transportation system depends on it.
4. Direct liquefaction and pyrolysis.
5. From burning coal.

Activity 4

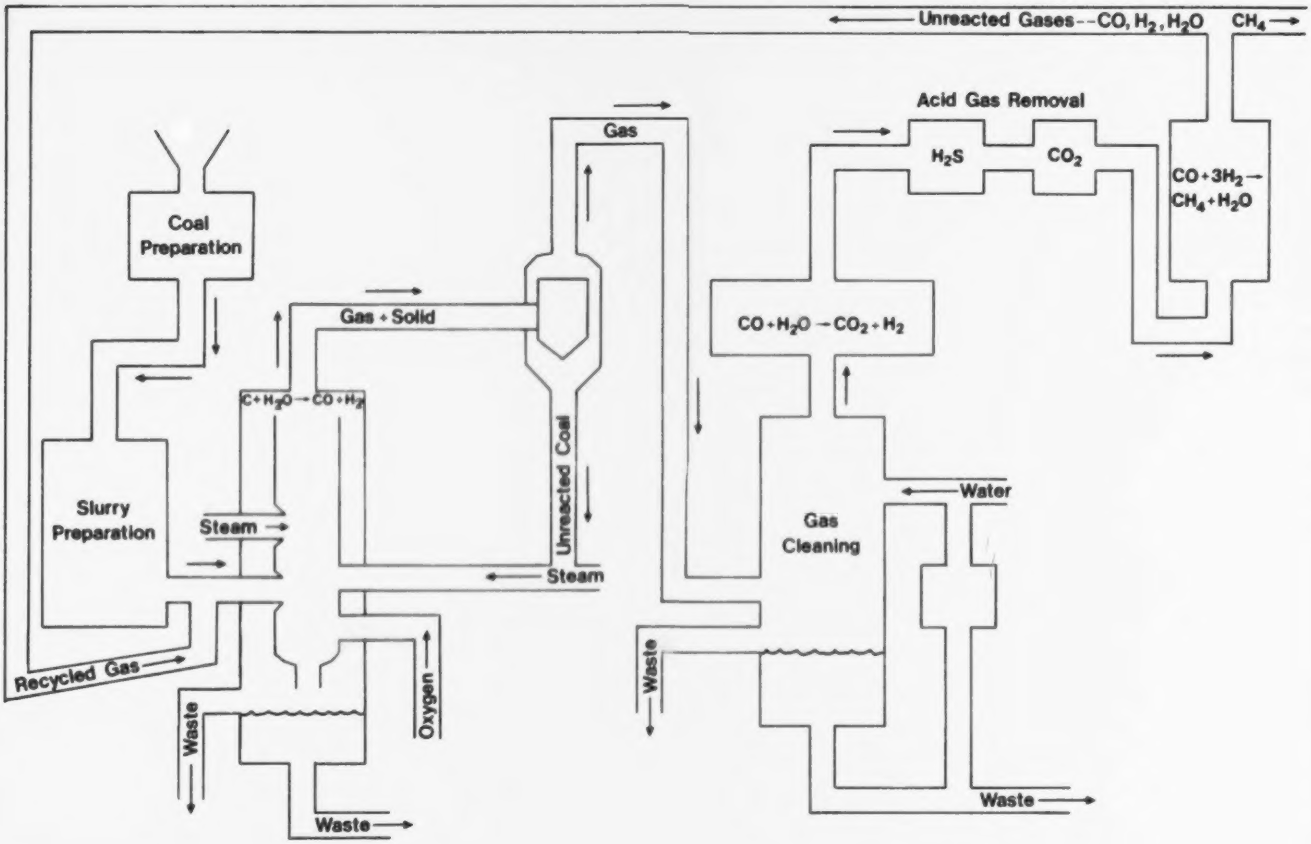
Begin this activity by displaying a transparency of the "Emissions Flow Chart," found in Student Handout 6–4.

You may want to clarify some of the terms used on the chart such as trace elements, catalysts, NO_x, SO_x, leachates, phenols, etc. Then distribute Student Handout 6–4, "The Environmental Effects of Synfuel Production," and have students answer the questions independently, in groups, or as a class.

Answers to Student Handout 6–4

A. 1. Storage, preprocessing, gasification, liquefaction.
   2. Workers breathing these materials could develop black lung.
   3. The temperature could be reduced.
   4. They reduce (but do not eradicate) emissions.
   5. Preprocessing and gasification/liquefaction.
   6. Sulfuric acid, matches, etc.
   7. Because coal is used up in synfuels production as well as consumption, giving off additional CO_2.
   8. The polar ice caps could melt causing extensive coastal flooding; agricultural patterns could change; the amount of desert area at the equator might increase; any of these changes would cause economic shifts and upheaval.
   9. Workers in synfuels plants.

Producing High Heat Value Gas From Coal


Unreacted Gases--CO, H_2, H_2O
CH_4
Acid Gas Removal
H_2S
CO_2
$CO + 3H_2 \rightarrow CH_4 + H_2O$
Gas
Coal Preparation
Gas + Solid
$C + H_2O \rightarrow CO + H_2$
$CO + H_2O \rightarrow CO_2 + H_2$
Unreacted Coal
Slurry Preparation
Steam
Steam
Water
Gas Cleaning
Recycled Gas
Waste
Oxygen
Waste
Waste
Waste

B.10. Preprocessing, gasification/liquefaction.
11. Irrigation of crops, municipal and other industrial water supplies.
12. Test substances to determine the safety of leaching.
13. Sulfur, phenols, ammonia, tars, oils, gas or liquid synfuels.
14. They are dumped in landfills. It adds to the cost.

C.15. a. Reclaiming land, acid mine drainage.
  b. Black lung, mine collapse, fires, acid mine drainage.
  c. Disruptive, increase in car-train accidents, expensive, and energy-consuming.

After students have completed the questions, you may want to discuss some of the other implications of building a synfuels plant. Some topics that could be discussed include land use, effects on the community, and overall effects on the water supply.

Extending the Learning

One of the effects of burning any fossil fuel is the greenhouse effect. You may want to go into this concept in more detail. In particular, students could directly compare the carbon dioxide concentrations from burning coal versus burning synthetic fuels. Students could also compare the cost of controlling emissions from a synfuels plant and from a coal-burning power plant.

SOURCES

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Student Handout 6–1

Gasifying Coal in the Laboratory

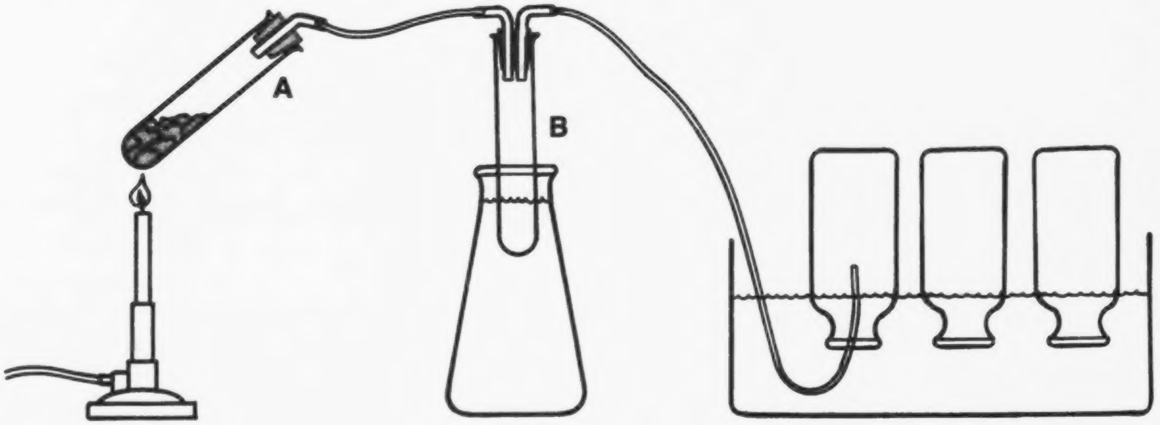
The purpose of this experiment is to show one of the processes that can be used to decompose coal into flammable gaseous products.

Coal is an extremely complex solid organic substance that was formed over millions of years from partially decomposed organisms. It is used to produce electrical power and to fuel industry. If coal is to be widely used in other ways to replace precious natural gas and petroleum, it will have to be converted to cleaner and more convenient forms.

One conversion process that is being explored is the *gasification of coal*. There are several different methods for producing gaseous fuels from solid coal. One of the methods is the *destructive distillation* of coal, accomplished by strong heating in the absence of oxygen. You will demonstrate this process in the following experiment.

PROCEDURE

1. Put on your safety goggles.
2. Mark one of the test tubes "A" and the other test tube "B."
3. Find the mass of the empty test tube A (nearest .01 gram). Record the mass in the data table.
4. Use the mortar and pestle to crush about 20 grams of soft coal into a fine powder. (You should have between 18 and 22 grams of coal.) Place the coal in test tube A. Find the mass (nearest .01 gram) of the test tube with the coal. Record the mass in the data table.
5. Using glycerin as a lubricant, place the glass tubing into the appropriate rubber stoppers as shown in the diagram below.
6. Now find the mass of test tube B with its stoppers, glass tubing, and rubber tubing. Record the mass in the data table.
7. Place about 150 ml of water in the 250 ml beaker.
8. Place the three gas collecting bottles, full of water, into the pail in an upside down position. See your instructor for help if needed.
9. Set up the rest of the apparatus as shown in the diagram.
10. Before you begin heating, have your instructor check your setup. Once it has been checked, start heating the coal slowly. Gradually add more heat and heat strongly for about 20 minutes, or until the third gas bottle is nearly full, whichever comes first. As soon as each gas collecting bottle becomes full of gas, cover and remove from the pail. If the last bottle does not completely fill, be sure to mark the level of gas.
11. While you are heating the coal, look at the data table and answer questions 4 and 5.
12. Before removing the heat from test tube A, be sure to take the rubber tubing out of the gas collecting pail to avoid back pressure.
13. Allow the apparatus to cool down. When cool, find the mass of test tube A, with its coal residue, and of test tube B, with its stoppers and tubing. Be sure to wipe off any water on the outside of test tube B and the rubber tubing before finding the mass. (Test tube B is used to collect any liquid products of the reaction.) Record the masses in the data table. Save test tube B for further testing.
14. Test the pH of the substance collected in test tube B using pH paper. Record the pH in the data table.
15. Describe the appearance of the residue in test tube A, the substance in test tube B, and the gas, in the data table.
16. Measure the total volume of gas collected, using a large graduated cylinder. Record in the data table. If you are unsure of how to measure the gas, check with your instructor.
17. Finally, test the flammability of the gas collected by holding a lighted wood splint over the top of the bottle. Remove the



cover. Record your observations in the data table.

18. Clean up all of your equipment and put it away, then begin work on the calculations.

Sample Data Table

1. Mass of test tube A when empty: ________ g
2. Mass of test tube A with coal: ________ g
3. Mass of test tube B with tubing: ________ g
4. Describe what is happening in test tube A while it is being heated: ________
5. Describe the appearance of the glass tubing during heating: ________
6. Mass of test tube A after heating: ________ g
7. Mass of test tube B with tubing after heating: ________ g
8. What is the pH of test tube B? ________
9. Describe the substances (color, odor, etc.) that are left after heating in:
   Test tube A ________
   Test tube B ________
   Gas bottles ________
10. Total volume of gas collected: ________ ml
11. What happens when the lighted splint is placed above the gas?

CALCULATIONS

Use another sheet to show your work.

a. Mass of coal at start: ________ g

b. Mass of *solid* remaining after heating: ________ g

c. Mass of *liquid* in test tube B with tubing: ________ g

d. Mass of *gas* produced: ________ g

e. Percent of solid products: ________; liquid products: ________; gas products: ________

f. Approximate molecular weight of gas (use 22.4 liters/mole to calculate) ________

QUESTIONS

1. Look at the pH of the substance produced in test tube B. What kind of substance was produced?
2. The gas that was collected in the experiment was a mixture of *some* of the following gases: CO_2 (MW = 44), CO (MW = 28), CH_4 (MW = 16), SO_2 (MW = 64), C_2H_6 (MW = 30), H_2 (MW = 2). From your calculation of the approximate molecular weight of the gas, which of the above is most likely to have been present?
3. Look at the proportional amount of flammable gas that was produced. Do you think this method would be an efficient way of producing gas from coal on an industrial scale? Why or why not?
4. Judging from the odors in the laboratory, what kinds of environmental problems could result from gasifying coal?
5. If you heated the coal for a longer period of time, do you think that you would produce significantly more gas? Why or why not?

Student Handout 6–2
Gasifying Coal Commercially

PART ONE

Many different industrial processes can be used to convert coal into a gaseous fuel. Some of the processes are still being developed, but others already are producing gas commercially. Some processes, in fact, have been in use for many years. In the mid-nineteenth century, coal was used to make both kerosene and "town gas" (or "water gas"). Town gas was used for cooking and lighting before petroleum and electricity were common. Today, interest in coal gasification is reviving because supplies of oil and natural gas are dwindling. Gases burn cleaner than solid coal and are easier (and therefore cheaper) to ship.

Coal is gasified in steps. The process can be shown as a series of chemical reactions. The first step in the gasification process is the reaction of the coal with steam heat under high pressure and temperature.

$$C + H_2O \xrightarrow{heat} CO + H_2$$

That is, coal and steam will react to form carbon monoxide and hydrogen. The heat comes from burning some of the coal.

The resulting mixture of CO and H_2 is called "synthesis gas" or "producer gas." This mixture has a heat value of approximately 2700 kcal/m^3. If the reaction takes place in air, the synthesis gas will have a lower heat value—about 890–1330 kcal/m^3. If the reaction takes place in pure oxygen, the heat value of the gas can be raised to 2700 kcal/m^3. Gases with both low and intermediate heat values are usable, but because their heat value is still lower than that of natural gas (8900 kcal/m^3), their usefulness is limited.

The next step in the gasification process improves the heat value of synthesis gas. In the presence of a catalyst, the following reaction can take place.

$$CO + 3H_2 \xrightarrow{catalyst} CH_4 + HO$$

That is, carbon monoxide and hydrogen reacted in the presence of a catalyst will form methane and water. However, this reaction needs more hydrogen than the amount available from the first reaction. The additional hydrogen can be obtained from an intermediate reaction (a reaction that must happen before the reaction above that produces methane).

$$CO + H_2O \xrightarrow{heat} CO_2 + H_2$$

That is, carbon monoxide and steam will react to form carbon dioxide and hydrogen. The CO_2 can be removed using an acid gas cleaning operation which will also remove H_2S, a by-product of the sulfur impurity.

The hydrogen from the intermediate reaction is added to the carbon monoxide and hydrogen from the first reaction, resulting in a combination of methane and water. The water is removed easily by cooling the gas. The formulated methane has the same heat value as natural gas (8900 kcal/m^3) and can replace it in a pipeline.

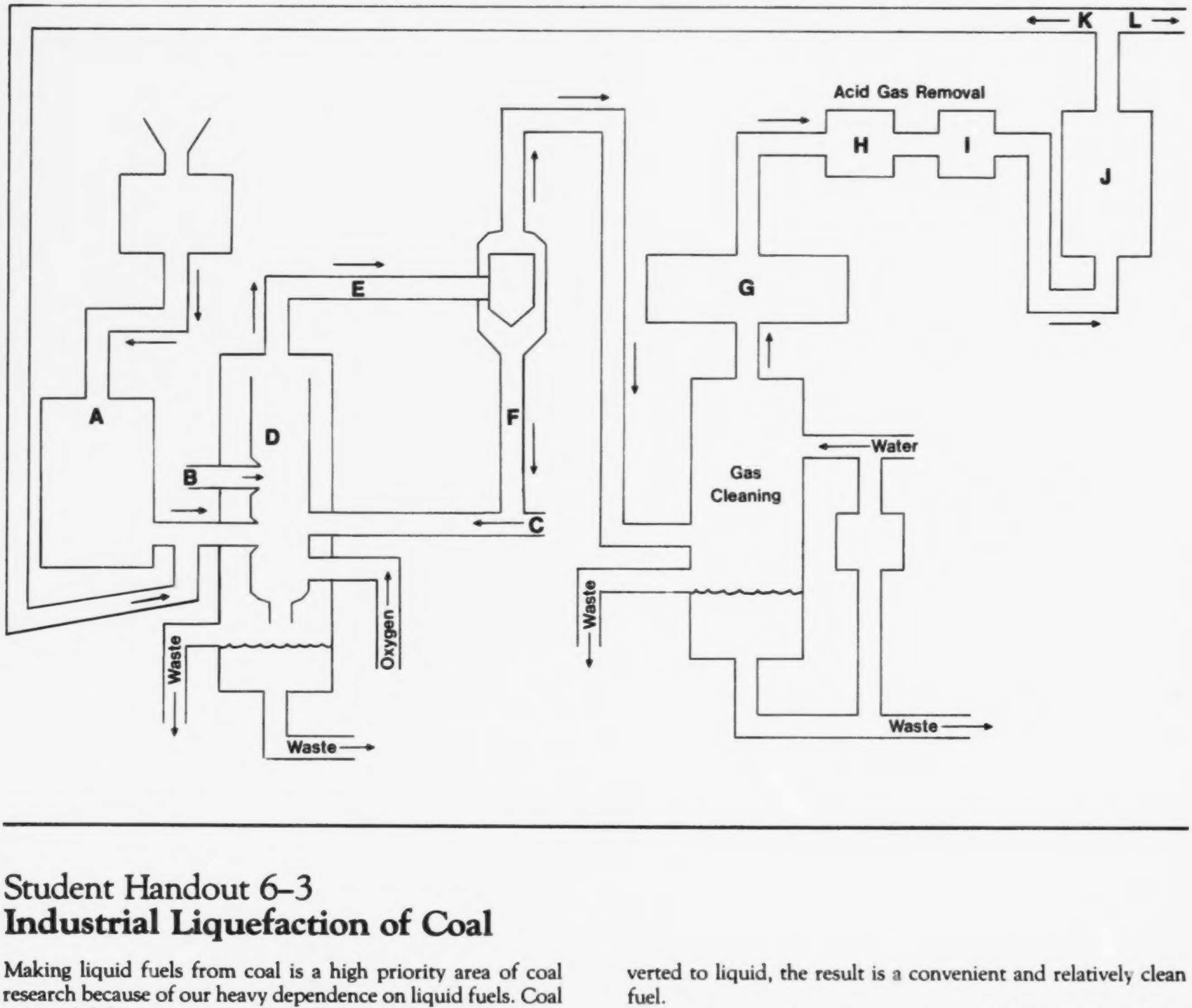
PART TWO

While the coal gasification process appears to be fairly simple on paper, it is very important to remember the complex molecular structure of coal. The composition of coal molecules varies enormously. Coal is made up mostly of carbon, but it also contains hydrogen, sulfur, oxygen, nitrogen, and other elements. When the coal is reacted with steam in producing the gases, many other chemical substances are produced. Some of the possible by-products are hydrogen sulfide, hydrogen cyanide, phenols, oils and tars, and trace quantities of lead, arsenic, and mercury. Some of these products can be recycled back into the gasification process.

Look at the following diagram of one coal gasification process for substitute natural gas. Answer the questions.

1. What is the substance found at A?
2. The same substance enters the process at both B and C. What is it?
3. What is the reaction that occurs in D?
4. At E there are solid particles and gas. What gases are present at E?
5. At point F, a solid has been separated by gravity and will reenter the reaction vessel. What is this solid?
6. In G, what reaction must be taking place?
7. At H and I, the acid gas cleaning process is underway. What two gases will be removed by this gas cleaning process?
8. At J, the final reaction will take place. What is the reaction?
9. What is the name of the gas drawn off at L?
10. The gases at K are being returned to the reaction vessel. Which gases are there?

Producing High Heat Value Gas From Coal



Student Handout 6–3
Industrial Liquefaction of Coal

Making liquid fuels from coal is a high priority area of coal research because of our heavy dependence on liquid fuels. Coal in its solid form is inconvenient and dirty. When coal is converted to liquid, the result is a convenient and relatively clean fuel.

There are four basic processes by which coal is liquefied:

solvent extraction, direct liquefaction, indirect liquefaction, and pyrolysis. These four are summarized below.

SOLVENT EXTRACTION PROCESS
Pulverized coal is mixed with a solvent. The slurry that results is mixed with hydrogen and heated to approximately 450° C at a pressure of about 70 atmospheres. The high temperature and pressure allow all of the organic constituents of coal to dissolve in the solvent. The mixture is broken into simpler components (cracked) producing hydrocarbons with relatively low molecular weight. Most of these products are liquids and can be refined into other useful fuels.

DIRECT LIQUEFACTION
Pulverized coal is mixed with hydrogen at approximately 450° C and 210 atmospheres pressure. This reaction is a catalytic process in which the coal and hydrogen react to produce primarily low molecular weight hydrocarbons. These products, principally liquids, can be refined into other fuels.

INDIRECT LIQUEFACTION
There are two major steps in this process. In the first step, coal is gasified to produce carbon monoxide and hydrogen. Then, as in the making of substitute natural gas, this synthesis gas must be enriched with hydrogen. Therefore, some of the carbon monoxide is reacted with water to produce more hydrogen and carbon dioxide. As in the gasification process, the carbon dioxide must be removed. Then the second step of indirect liquefaction takes place. Carbon monoxide and hydrogen are recombined in the presence of a catalyst under high temperature and pressure (900° C, 80 atm), to form a liquid. Obviously, this method is much less efficient than solvent extraction or direct liquefaction.

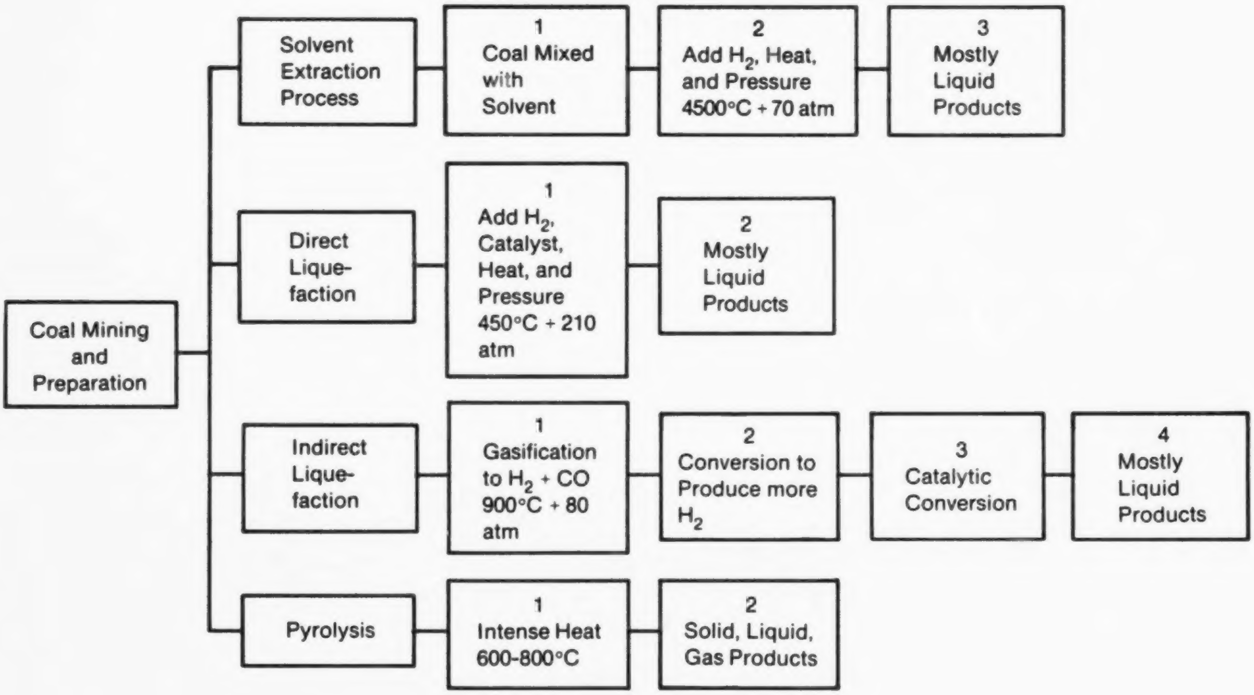
PYROLYSIS
Coal is heated in the absence of oxygen to 600°-800° C. The very large coal molecules are cracked into smaller hydrocarbon molecules. There is not enough hydrogen in the coal to convert all of the carbon to simple hydrocarbons; as a result, pyrolysis produces solid wastes called char, as well as liquid and gaseous fuels. (Char is useful as a fuel also to some extent.)

None of these coal liquefaction processes are in commercial use in the United States today. In South Africa, however, indirect liquefaction has been used successfully since 1955. Most experts agree that solvent extraction and direct liquefaction are the most promising processes for coal liquefaction in the future. Indirect liquefaction and pyrolysis do not seem to be commercially viable.

Use the reading and the diagram to answer these questions.

1. Look at all four processes. What are some common features of all of the processes?
2. If the object of these processes is to produce liquid fuel, which process gets the poorest results?
3. In the indirect liquefaction process, a gas is produced as an intermediate product. What is the reason for lengthening the process to produce a liquid rather than collecting the gas?
4. Process efficiency depends on the efficiency of each step in the process and on the number of steps. Based on this information, which processes should be the most efficient?
5. In each of the processes, a great deal of heat is needed. Where do you think that heat will come from?

Flow Chart for Liquefaction Techniques

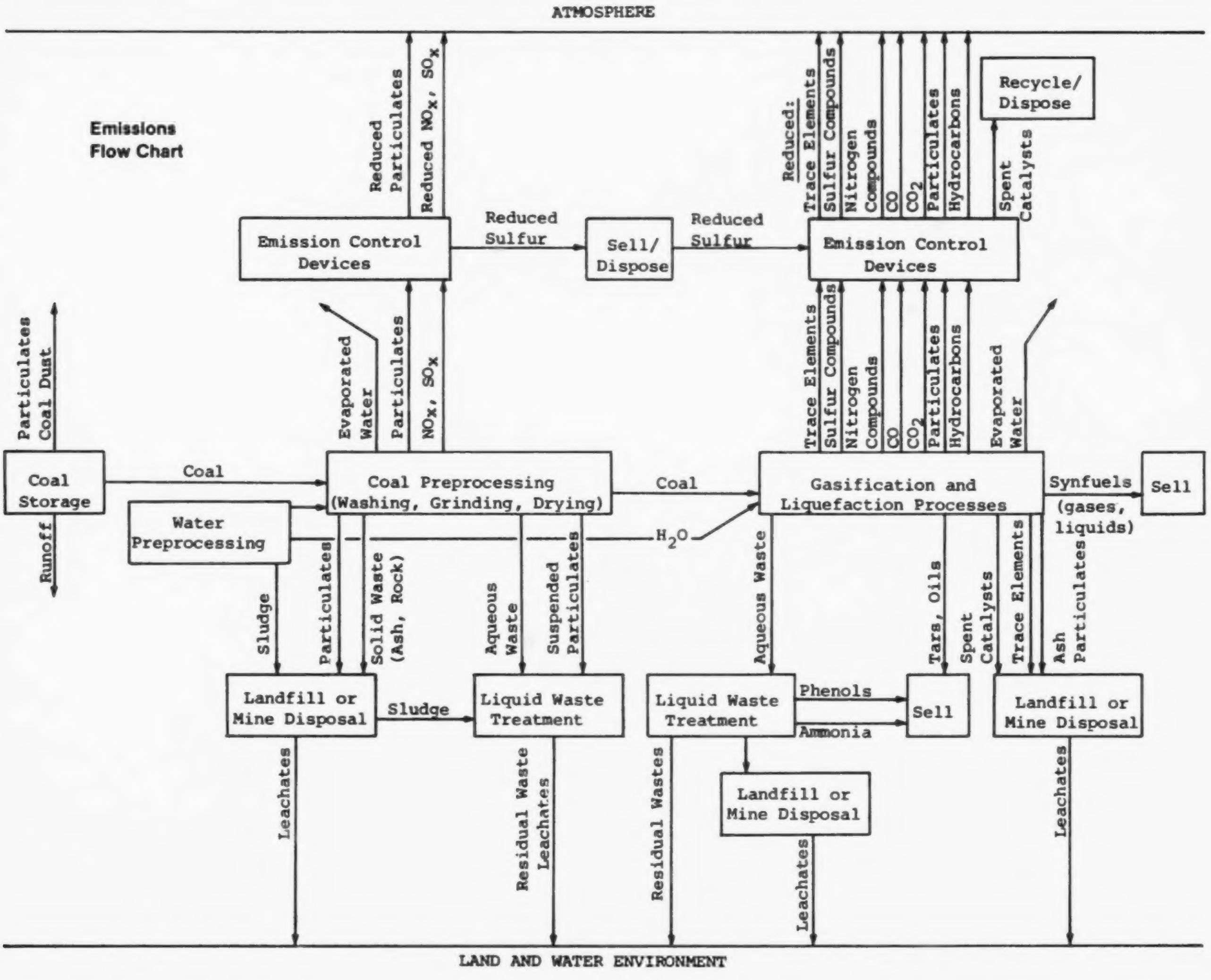

Coal Mining and Preparation
Solvent Extraction Process
1 Coal Mixed with Solvent
2 Add H_2, Heat, and Pressure 4500°C + 70 atm
3 Mostly Liquid Products
Direct Lique-faction
1 Add H_2, Catalyst, Heat, and Pressure 450°C + 210 atm
2 Mostly Liquid Products
Indirect Lique-faction
1 Gasification to H_2 + CO 900°C + 80 atm
2 Conversion to Produce more H_2
3 Catalytic Conversion
4 Mostly Liquid Products
Pyrolysis
1 Intense Heat 600-800°C
2 Solid, Liquid, Gas Products

Student Handout 6–4
Environmental Effects of Synfuels Production

Use the Emissions Flow chart to answer the following questions.

A. *Atmospheric Emissions* (arrows going up):

1. Particulates are pieces of solid material so small that they can float up into the atmosphere. Look at all of the processes shown. In which processes do particulates appear as emissions?
2. What are some of the possible health hazards associated with the coal dust and particulates from coal storage?
3. Some scientists have expressed concern about the buildup of particulates in the atmosphere. If enough particulates accumulate, they could cause some of the sun's radiation to be blocked. What could happen to the global temperature if this occurs?
4. There are two emission control devices pictured in the chart. What is their effect on emissions from gasification and liquefaction processes?
5. Acid rainfall is a problem that is associated with the buildup of sulfur and nitrogen compounds (particularly sulfur and nitrogen oxides—SO_x and NO_x). Which processes produce emissions of sulfur and nitrogen compounds?
6. The sulfur collected by emission control devices can be a useful by-product. Suggest one use for sulfur compounds.
7. Burning coal directly produces carbon dioxide. In fact, burning most carbon compounds will produce carbon dioxide. The gas is not controlled by emission control devices. Why does the use of synfuels made from coal produce more carbon dioxide than the direct burning of coal?
8. The accumulation of carbon dioxide in the upper atmosphere may pose another climatic problem known as the greenhouse effect. This CO_2 holds the sun's heat, just like glass in a greenhouse. Many scientists believe that if levels of carbon dioxide continue to rise, the additional heat retained


ATMOSPHERE
Emissions Flow Chart
Reduced Particulates
Reduced NO_x, SO_x
Reduced: Trace Elements
Sulfur Compounds
Nitrogen Compounds
CO
CO_2
Particulates
Hydrocarbons
Recycle/ Dispose
Spent Catalysts
Emission Control Devices
Reduced Sulfur
Sell/ Dispose
Reduced Sulfur
Emission Control Devices
Particulates Coal Dust
Evaporated Water
Particulates
NO_x, SO_x
Trace Elements
Sulfur Compounds
Nitrogen Compounds
CO
CO_2
Particulates
Hydrocarbons
Evaporated Water
Coal Storage
Coal
Coal Preprocessing (Washing, Grinding, Drying)
Coal
Gasification and Liquefaction Processes
Synfuels (gases, liquids)
Sell
Water Preprocessing
H_2O
Runoff
Sludge
Particulates
Solid Waste (Ash, Rock)
Aqueous Waste
Suspended Particulates
Aqueous Waste
Tars, Oils
Spent Catalysts
Trace Elements
Ash Particulates
Landfill or Mine Disposal
Sludge
Liquid Waste Treatment
Liquid Waste Treatment
Phenols
Ammonia
Sell
Landfill or Mine Disposal
Landfill or Mine Disposal
Leachates
Residual Waste Leachates
Residual Wastes
Leachates
Leachates
LAND AND WATER ENVIRONMENT

may cause an increase in global temperatures. What are some of the global problems that could arise if the average world temperature were to increase slightly?

9. In the process of producing synfuels, a group of compounds called polycyclic aromatic hydrocarbons (PAH) is formed. These compounds are known to be carcinogenic (cancer-causing) agents. What group of people will probably be most affected by the presence of PAH compounds?

B. *Emissions Affecting Land or Water:*

10. In which processes is water used?
11. It is estimated that liquefaction plants will use between 100 and 200 gallons of water for every million kilocalories of energy produced. Much of the coal in the United States is in the arid areas of the southwest and north central plains. With what current uses of water will synfuels production conflict?
12. Leachates and residual wastes from coal conversion will be allowed to seep into the ground. How can the drinking water supply near the synfuel plants be protected?
13. What products and by-products of the coal conversion process can be collected and sold?
14. Many of the solid wastes, if dumped directly on the ground surface, will alter soil chemistry. What is done with those solid wastes in the flow chart? What effect does this method of disposal have on the cost of producing synfuels?
15. Because synfuels are made from coal, all of the environmental problems associated with coal production must be considered. What are some of the problems associated with:
    a. Surface mining?
    b. Underground mining?
    c. Transportation?

Lesson 7

The Second Law of Thermodynamics

Heat engines power our industrial society; but the efficiency of converting heat energy to the mechanical energy which our society depends on is very low. In this lesson, students will learn from demonstrations, class discussion, and problem sheets that the First Law of Thermodynamics does not require this low efficiency, nor can ideal efficiency be reached by using energy conservation strategies. There is another law of nature in operation; the Second Law of Thermodynamics.

OBJECTIVES

Students should be able to:

- Give examples of energy conversions that allow 100 percent efficiency.
- State the operating principle of a heat engine.
- Give reasons why the efficiencies of heat engines are low.
- Explain why heat engines are important in today's society.
- Calculate the maximum efficiency possible for a process that converts heat energy to mechanical energy.
- Understand the relationship between energy and temperature.
- State the Second Law of Thermodynamics.

TARGET AUDIENCE

Students of Chemistry, Physics

TIME ALLOTMENT

Three to five class periods

MATERIALS

Student Handout 7-1, "Building a Small Heat Engine"
Student Handout 7-2, "Temperature and Energy Density"
Student Handout 7-3, "Energy Density"
Student Handout 7-4, "A Paddle Wheel Heat Engine"
Student Handout 7-5, "The Second Law of Thermodynamics"
Student Handout 7-6, "Measuring Maximum Efficiencies of Heat Engines"

Activity 1
One 3 or 6 VDC hobby motor (available at most hobby or electronics parts stores)
One sub-mini light bulb (rated 1.5V at 15 to 25 mA)
One tin can lid
One small rubber grommet
One pressure cooker
One one-burner hot plate
Two ring stands (for generator and to hold medicine dropper)
Two utility clamps
One medicine dropper
One length of rubber tubing
Template for a turbine blade
Scissors or tin snips
Double-stick tape
Long-nose pliers

Activity 2
(Required for each group of four students if done as a lab rather than as a teacher-led demonstration)
Two 400-ml beakers
Two alcohol burners (same size)
Water
Two raw eggs (same size)
Two thermometers
Two bowls
Two wire stands
Matches
Methanol
Metric ruler

Activity 3
Four immersion heaters
Graduated cylinder
Four 600-ml beakers
Water
Thermometer
Graph paper
Rulers
Pot holder or beaker tongs

Activities 4 through 6
One steam generator
One turbine motor
One alcohol burner
One ring stand and clamp
Two 150°C thermometers

BACKGROUND INFORMATION

The Second Law of Thermodynamics sets an upper limit on the efficiency of any process that converts heat energy to mechanical energy, regardless of the method used in the process. Although energy conservation measures can raise the efficiency of heat engines, maximum efficiency depends on the temperature difference between the heat energy input and the environment to which the remaining heat energy is discharged. The Second Law of Thermodynamics states: *It is not possible to convert all of a given amount of heat energy into mechanical energy in the cyclic fashion typical of an engine.*

Sometimes the First Law of Thermodynamics is compared to the proverb: "You can't get something for nothing." In the same vein, the Second Law might be stated: "You can't even break even!"

Some classes may need reminding that heat is really the kinetic energy of molecules. The hotter the substance is, the faster the molecules are moving. Heat energy is converted to work (mechanical energy) by molecules pushing against the moving part of a machine.

TEACHING STRATEGIES

Review the First Law of Thermodynamics before you begin the lesson. Tell students that although the efficiency of heat engines can be improved, the upper limit of efficiency of a heat engine depends on the temperature difference between the heat source and the surroundings.

Next, point out that there are energy conversions that are 100 percent efficient, if heat is the final form of energy desired. Ask students to rub the palms of their hands together. Almost all of the mechanical energy from this motion is converted to heat between their hands due to friction (a tiny amount of energy goes into sound). Then illustrate another 100 percent efficient conversion by placing an electric immersion heater into a container of water. Ask: How can this be a 100 percent efficient conversion? (Because a certain amount of energy was put into the water and only heat was produced.) How are these two demonstrations alike? (Both are almost 100 percent efficient and, in both, heat is the final form of energy obtained.) How are they different? (The first is a mechanical to heat conversion, and the second is an electrical to heat conversion.) If water is heated with an immersion heater in a well-insulated container, the 100 percent efficiency can be proven by a comparative measuring of energy input and output.

Activity 1

Several days ahead of time, assemble the materials and build (or help interested students build) the model heat engine presented in the student guide. Make sure the model works properly before demonstrating it in class.

After the class has seen the engine work, have the students complete Student Handout 7-1. Immediately after demonstrating the heat engine, you may wish to discuss the questions on the handout with the whole class for greater understanding.

Answers to Student Handout 7-1

Sample Calculations:

Power Input = 1100 watts

Power Output = 1.5 volts × 0.015 amps = 0.0225 watts

Efficiency $= \frac{0.0225}{1100} \times 100\% = 0.002\%$

1. A lot of heat is "lost" to the surroundings at the hot plate and pressure cooker; much of the steam's energy is lost as it shoots sideways after it is deflected from the turbine blades. Some steam misses the turbine altogether; frictional losses in the turbine and generator cut down the efficiency.
2. It is true that engineering know-how can be used to greatly increase efficiency. (Insulation, steam recycling, and friction reduction are three obvious strategies.) However, because of the energy conversions taking place that do not produce work, engine design can compensate for the inefficiency of energy conversions only up to a certain point. The upper limit of efficiency is enforced in most of these cases by friction and heat "loss," which operate no matter what work is to be done or what means are employed to do the work.
3. Heat engines are popular because we often need mechanical energy, yet fuels usually supply only heat energy.

Activity 2

With this egg experiment (Student Handout 7-2) we investigate the relationship between energy and temperature. The same amount of energy is put into each beaker but produces different physical effects (in one case the egg is cooked, in the other it isn't). Why? The different volumes of water must be the key. In the beaker with less water the energy was shared among fewer molecules and therefore gave them higher average kinetic energy. On contact with the egg the higher energy molecules were able to transfer more energy per collision and thus cook it faster. We say the molecules were hotter and measure this average kinetic energy as temperature.

Answers to Student Handout 7-2

1. Yes.
2. No, because the volumes of water being heated were different.
3. It will be higher in the beaker with less water because the energy is shared by fewer molecules.
4. The egg in the shallower water is more fully cooked than the egg in the deeper water. The more energetic molecules could give up more energy to the egg and thus cook it faster.
5. Yes, temperature is higher in the beaker in which the molecules have higher average energy. Note: Since the same amount of heat was supplied to each beaker, students should observe that the change in temperature (ΔT) is inversely proportional to the mass of the water (M):

$$\frac{\Delta T_1}{\Delta T_2} = \frac{M_2}{M_1}$$

Ask students to do an energy input/output study for the alcohol lamp-beaker system similar to the one performed on the power plant flow system. The energy input comes from the alcohol consumed. Look up the heat of combustion in a handbook of chemistry and physics. Simplify the output by considering only the water in the beaker. The students should recognize that heat energy is also stored in the beaker, ring stand, and egg. Most of the heat loss will be to the air.

Activity 3

This activity is also designed to show a relationship between the average molecular kinetic energy and temperature. The data gathered in this experiment lend themselves to making simple graphs to extend the learning.

Begin by placing the following question on the chalkboard: *Can materials containing the same amount of energy have different energy densities?*

Next, distribute graph paper, Student Handout 7-3, and enough materials for small groups to work with, or use the materials yourself in a demonstration. The procedure is outlined in Student Handout 7-3.

Answers to Student Handout 7-3

1. Yes.
2. No.
3. It is a straight line.
4. Answers will vary.
5. All four beakers have approximately the same heat content.
6. Beaker #1, because it contains the greatest amount of energy per unit of volume.

Activity 4

Distribute Student Handout 7-4. In this activity, students describe the Second Law of Thermodynamics at work. We suggest that you use the activity as a homework assignment, but discuss the answers to the questions as fully as possible in class. End the discussion by writing the Second Law on the chalkboard.

Before you assign the activity as homework, tell students that the picture illustrates a type of machine called a paddle wheel heat engine. Theoretically, the box is so perfectly insulated that once the hot gas is put in the left chamber, no energy can enter or leave the box. The temperature equals the average kinetic energy of the molecules of a substance. The paddle wheel heat engine converts heat energy to mechanical energy.

Answers to Student Handout 7-4

1. The molecules of the hot gas move faster than the cold molecules and force the paddle wheel to rotate clockwise.
2. It gets dimmer. In a given amount of time, more and more hot gas molecules enter the right-hand chamber. Eventually they are at the same density in both chambers. Then the direction of flow changes. Molecules flow from the right chamber to the left as well as in the other direction, and the paddle wheel slows down and eventually stops.
3. a. No. The engine is insulated from the outside.
   b. As time goes on, the ability of the engine to do useful work decreases. We say that energy usefulness is lost.
4. Heat flows from the region of higher temperature to the region of lower temperature.
5. Yes.
6. a. Yes, almost all of the original energy remains in the box. Only a small amount escapes as light.
   b. For heat energy to be converted to work, a difference in temperature must exist.
7. 2, 3, 1.
8. When work is done, some of the useful high temperature mechanical energy is converted by friction to less useful, lower temperature heat. In warming an object, heat flows from a warmer to a cooler region and again becomes less useful because of its lower temperature.

Answers to Questions for Extended Thinking

1. a. The heat would flow out of the coffee into the air, i.e., from a hot area to a cooler area.
   b. The heat would flow from the warmer water into the ice cubes, thereby melting the ice.
   c. Eventually both the hot coffee and the ice water would reach room temperature.
2. The paddle wheel.
3. The temperature difference between the hot and cold gases.
4. The temperatures would be about the same.
5. Yes, it will stop moving eventually because the hot gas mixes with the cooler gas, their temperatures become the same, and the flow stops.
6. Yes, the molecules possess the same amount of energy that has been present in the box all along. It is the usefulness of the energy that has decreased.
7. The only way to make the paddle wheel turn again would be to add energy from outside the system, heating or cooling one side to reestablish the temperature difference.
8. Since all the gas has the same temperature, no flow of heat energy is occurring and therefore work cannot be done.
9. c.

Activity 5

Students should now understand that the Second Law of Thermodynamics limits the efficiency of heat engines to less than 100 percent. They should know that the higher the temperature of the energy source above the temperature of the machine's surroundings, the more efficient the energy conversion from heat to work. This is true no matter what type of machine or heat source is chosen to do the job.

Distribute Student Handout 7-5 and review the information with students. Be sure they understand the development of the equation used to find the maximum possible efficiency of a heat engine.

Answers to Student Handout 7-5

1. Zero.
2. No, T_2 would have to be at absolute zero, which is unattainable.
3. Infinity (∞).
4. No, $T = \infty$ is also impossible.

Activity 6

Distribute Student Handout 7-6. The students calculate the efficiency limit of two heat engines as set by the Second Law. The first calculation involves the automobile engine. The second calculation uses the steam turbine-generator combination from Activity 1. Students will be asked to do their own measuring.

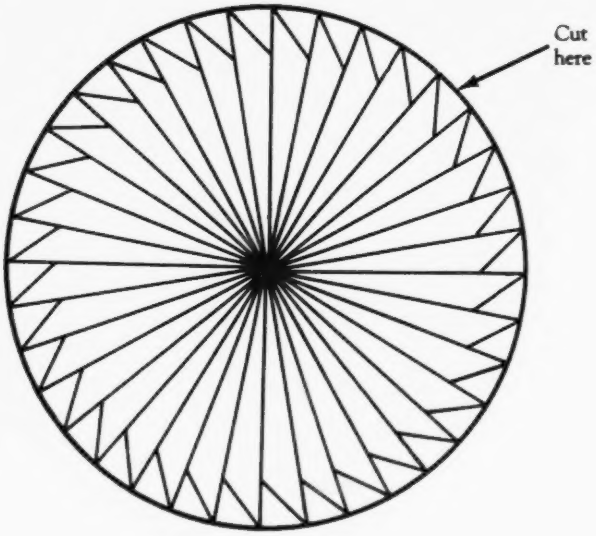
Answers to Student Handout 7-6

1. a. $1 - \frac{538 + 273}{2204 + 273} = 1 - \frac{811}{2477} = 1 - .33 \cong 67\%$
   b. Yes.
2. Answers will vary for T_1 and T_2.
3. $\cong$ 50 percent.
   a. Actual efficiency is much less.
   b. Heat loss at the hot plate and turbine.

Student Handout 7-1

Building a Small Heat Engine

Heat engines are the most important energy transfer devices in today's industries. They power our automobiles and produce the major portion of our electricity. In this activity, you will build a small heat engine, calculate its efficiency, and speculate why the efficiency is so low. Did you know that an electric motor run backward becomes an electric generator?



After the center hole is drilled, insert a small rubber grommet. If the hole in the grommet is larger than the motor shaft, build up the shaft size with masking tape until the turbine attaches snugly to the shaft. A screen retainer spline can also be used for snug fitting of the shaft and grommet hole. Some splines have a small hole in the center that encourages a good fit.

Complete the assembly as shown. CAUTION: Pressure cookers can be dangerous and steam is hot. Please use safety goggles.

Once the generator is running and the mini-lamp glows, the overall efficiency of the steam engine can be calculated as follows:

Power Input = wattage rating of the hot plate if set on "high"

= _________ watts

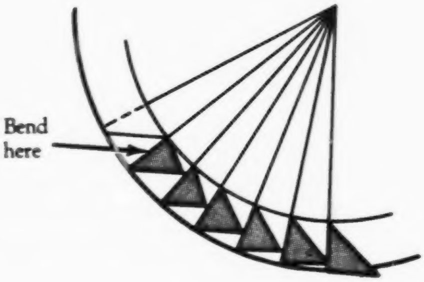
Power Output = _________ volts × _________ amps

(of mini-lamp) = _________ watts

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} \times 100\%$$

= _________%

First, cut the turbine blade from a tin can lid, using the design shown. The template should first be drawn on paper and then attached to the tin can lid with double-stick tape. The cuts can be made with scissors or tin snips. Bend the blades with long-nose pliers.



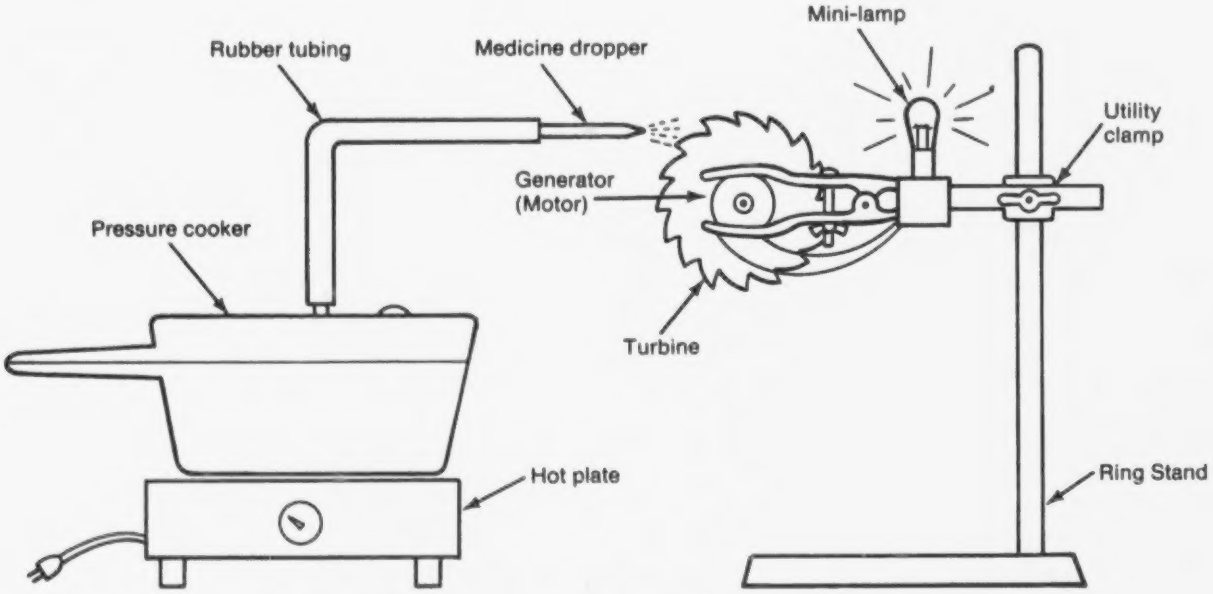
Note: In order to generate as much as 1.5 v with a motor driven as a generator, it will be necessary to use a motor rated at 3–6 v. The turbine cannot turn a 1.5 v motor fast enough to generate sufficient voltage to light a 1.5 v light bulb.

The efficiency you calculated is a general systems efficiency because it takes into account not only the efficiency of the desired heat to electrical energy conversion, but also the loss of heat at the hot plate and the loss of steam at the turbine.

QUESTIONS

1. Give several reasons why the efficiency of the generator is so low.
2. Could improvements in engine design enable the engine to reach 100 percent efficiency?
3. If heat engines are at present so inefficient, why are they so widely used?

Note: See next page for Figure 7-5


Mini-lamp
Rubber tubing
Medicine dropper
Utility clamp
Generator (Motor)
Pressure cooker
Turbine
Hot plate
Ring Stand

Student Handout 7-2

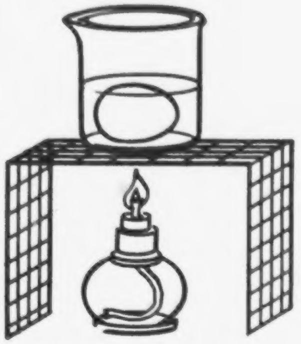
Temperature and Energy Density

The purpose of this experiment is to compare the heat energy densities of two different systems which have received the same amount of energy, and then relate them to temperature.

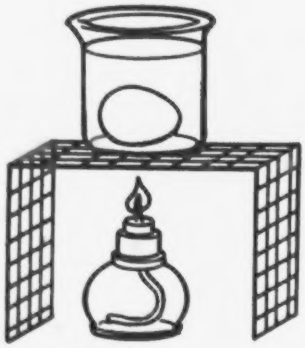
DIRECTIONS
Do the following experiment. Then answer the questions that follow.

PROCEDURE

1. Set up the apparatus as shown. Be sure that each alcohol burner contains the same amount of methanol, about 100 ml, and that the wicks are at the same height.
2. Record the initial temperature of the water in each beaker.
3. Light the burner.
4. After 20 minutes, extinguish the flame and record the water temperatures in each beaker again.
5. Break each egg into a separate bowl. Compare their physical condition.
6. Compare the levels of methanol left.



Beaker 1
Water just covers egg



Beaker 2
Water goes to brim

7. Record your observations.

	Beaker 1	Beaker 2
Beginning Temperature (T_1)	____°C	____°C
Final Temperature (T_2)	____°C	____°C
Final level of methanol	____ ml	____ ml

QUESTIONS

1. Was the same amount of chemical energy provided to each beaker?
2. Were the water temperatures the same at the end of the experiment? Why or why not?
3. The heat energy put into each beaker is transferred to the molecules of water as kinetic energy. In which beaker will the average kinetic energy of the molecules be higher?
4. How does the condition of the eggs support your answer to question 3?
5. Does temperature seem to be related to the average kinetic energy of the molecules?

Student Handout 7–3

Energy Density

PROCEDURE

1. Fill four 600 ml beakers with these amounts of water:

Beaker #1	100 ml of water
Beaker #2	200 ml of water
Beaker #3	300 ml of water
Beaker #4	400 ml of water

2. Place a thermometer in each beaker and record the temperatures on a chart. (See sample.)
3. Put all the beakers in the microwave oven. Start all volumes at the same temperature. Heat all at the same settings of time and temperature.
4. Turn off the oven, and remove the beakers with a pot holder.
5. Measure and record temperatures again.

DATA CHART

Beaker	Water (ml)	Beginning T (°C)	Final T (°C)
#1	100		
#2	200		
#3	300		
#4	400		

6. Make a graph of your results using volume as the *x* coordinate and temperature as the *y* coordinate.

QUESTIONS

1. Was the same amount of energy provided to each beaker?
2. Did all the beakers have the same final temperature?
3. Describe the shape of the curve.
4. Find the amount of heat energy in each beaker. Use the following equation.

$$\text{Heat content} = \text{mass } (H_2O) \times \text{change in temperature} \times 1\,\frac{\text{Cal}^*}{\text{g}}$$

(*1 Cal/g is the specific heat of water)

5. In one sentence, compare the heat content of the beakers.
6. Which beaker had the highest average molecular energy? Why?

Student Handout 7–4

A Paddle Wheel Heat Engine

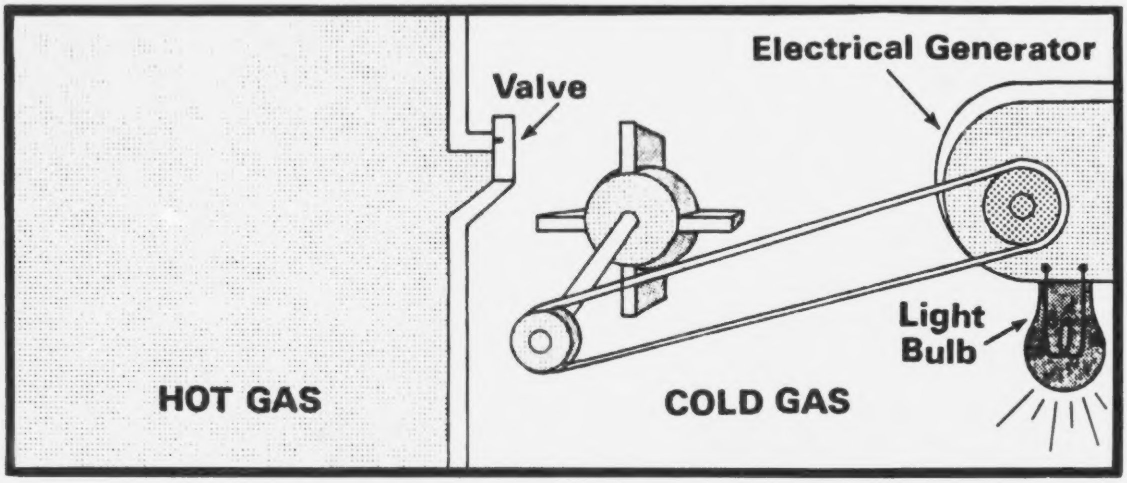
In any conversion of energy from one form to another, the usefulness of the energy always decreases.

Examine the idealized heat engine shown below. Then answer the questions that follow. The engine is enclosed in a perfectly insulated box and the wall between the chambers is a perfect insulator. Heat cannot enter or leave. The chamber at left contains a very hot gas; the chamber at right, very cold gas. The paddle wheel's axle is mounted and turns on frictionless bearings. Turning the generator and lighting the bulb require only a tiny amount of energy. To start the heat engine, open the valve.

QUESTIONS

1. Why does the bulb light when the valve is first opened?
2. What happens to the brightness of the bulb as time goes on? Why?
3. a. Is energy lost as time goes on?
   b. What does change over time?
4. In terms of temperature, what is the direction of heat flow in this experiment?
5. Is the heat flow spontaneous?
6. a. Once the bulb goes out, is there any heat energy left in the box?
   b. If you said yes to 6a, why does the bulb go out?
7. We rank energy usefulness in terms of the efficiency of conversion to mechanical work. Rank the following forms of energy by their usefulness: 1) low temperature heat energy; 2) gravitational potential energy; 3) high temperature heat energy.
8. Explain the following statement: In the performance of any task, the efficiency of the output energy is less than that of the input energy.

A Paddlewheel Heat Engine



QUESTIONS FOR EXTENDED THINKING

1. a. Suppose you left a steaming hot cup of coffee on the breakfast table. Can you describe the direction in which the heat energy would flow?
   b. Now suppose you dropped an ice cube into a glass of water. In which direction would the heat flow?
   c. What would be the final temperature of both the cup of coffee and the glass of water if you left them sitting for a long time?
2. In the paddle wheel heat engine, heat energy is converted to mechanical energy. What is the instrument of conversion?
3. What is the source of energy for the paddle wheel engine?
4. After a long period of time, how would the temperatures in both chambers of the insulated box compare?
5. Do you think the paddle wheel will stop moving eventually? Why or why not?
6. Do the gas molecules in both sides of the box still have heat energy?
7. What would be required to make the paddle wheel turn again?
8. If energy can be converted from one form to another, and if the gas still has heat energy, what prevents the rest of the heat energy from converting to mechanical energy?
9. Which of the following laws of nature does the law demonstrated in this exercise most closely resemble?
   a. Whatever goes up must come down.
   b. Opposite charges attract.
   c. Heat energy cannot be completely converted to mechanical energy.
   d. It is not possible to exceed the speed of light.

Student Handout 7-5

The Second Law of Thermodynamics

According to the Second Law of Thermodynamics, the maximum efficiency possible for any process that converts heat to mechanical energy is ultimately set by the temperature difference between the heat energy source and the machine's surroundings. This is true no matter what type of machine or heat source is chosen.

The following will help you to see why heat engines cannot be 100 percent efficient according to the Second Law.

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1}$$

T_1 = temperature of the energy source

T_2 = temperature of the surroundings

When $\frac{T_1 - T_2}{T_1} = 1$, then efficiency is 100%.

1. What value must T_2 have to give an efficiency of 1 (100%)?
2. Since temperatures must be measured on the absolute temperature scale, is it possible to attain this temperature?
3. What value must T_1 have to give an efficiency of 1 (100%)?
4. Can the T_1 needed in question 3 ever be attained?

The Second Law of Thermodynamics tells us that heat energy cannot be converted into mechanical energy with 100 percent efficiency. (To be completely accurate this statement must only be applied to a repeating process like that which occurs in an engine. 100 percent conversion can be achieved in a one-shot process.)

Why the efficiency of a heat engine depends so critically on this temperature difference is explained below.

Heat engines need a source of heat energy in order to work.

Heat energy flows from hot to cool, from high to low temperatures. Thus, a heat engine needs a source of high temperature heat energy. (The initial high temperature = T_1.)

Heat engines use a "working fluid" which absorbs energy from the high temperature source, carries this energy to the conversion machine, and then is discharged after giving up energy to the conversion machine. Steam is the working fluid in most electric power plants. It absorbs energy from the furnace boiler, causes the turbine to turn (converting some of its heat energy to mechanical energy), and then is discharged from the turbine as exhaust.

The working fluid still possesses energy after it has been discharged (the steam is still hot). If the working fluid is to be recycled—put through the process again—it must be returned to its original condition. (Steam must become water at room temperature.) This means that the working fluid must be cooled down to the temperature of the surroundings. It must reach the temperature T_2.

You may wonder why the hot steam can't be returned to the boiler as it is, saving the energy needed to cool it. If the steam is not cooled and condensed, then the turbine has to do work against that steam, to push it out of the way. This extra work reduces the efficiency. If it is cooled and condensed, however, the turbine turns in a partial vacuum and does very little work. A similar explanation holds for all heat engines.

The process in an ideal heat engine, one in which there are no losses due to friction, heat leakage, etc., is the following: An amount of heat energy (H_1) at a high energy density (T_1) is taken from a hot source. Some of this energy is converted into work, W; the rest, H_2, at a lower temperature (T_2) is rejected to the surroundings.

The First Law of Thermodynamics tells us that the amount of work done is just the difference between the heat energy input (H_1) and the heat energy output (H_2).

That is, $W = H_1 - H_2$. The efficiency is therefore:

$$E = \frac{\text{Work}}{\text{Energy Input}}, \text{ or}$$

$$E = \frac{W}{H_1}, \text{ so}$$

$$E = \frac{H_1 - H_2}{H_1} = 1 - \frac{H_2}{H_1}$$

If the working fluid is steam, then the amounts of high temperature heat energy, H_1, and low temperature heat energy, H_2, can be found by multiplying the average kinetic energy of the molecules by the number of molecules in the steam. As we have said and shown, the average kinetic energy of the molecules of a volume of steam is proportional to the temperature. Thus, H_1 depends on (is proportional to) n_1T_1, and H_2 depends on (is proportional to) n_2T_2, where n_1 and n_2 are the numbers of hot (n_1) and cool (n_2) molecules. But the number of molecules is the same: $n_1 = n_2$. They are not destroyed as they go through the turbine. In the ratio H_2/H_1, therefore, the ns cancel out and we get:

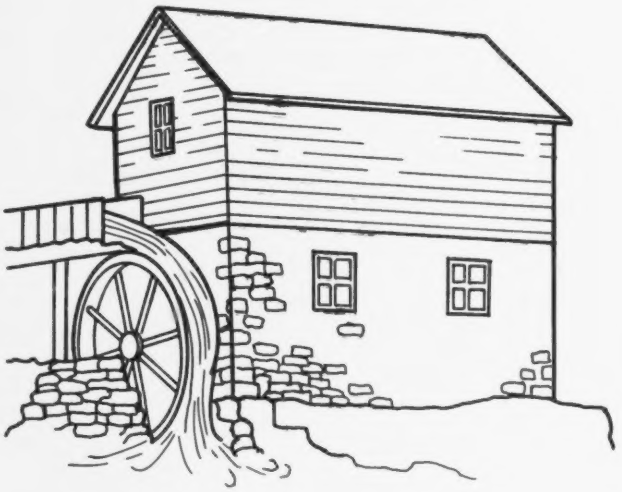
$$\frac{H_2}{H_1} = \frac{T_2}{T_1}, \quad E = \frac{T_1 - T_2}{T_1} \text{ or } 1 - \frac{T_2}{T_1}$$

Note: This is a highly simplified derivation and not a rigorous one. The result can be rigorously derived, of course.

Since a substance will have some energy (molecules move and thus have energy) all the way down to absolute zero, the temperature that we use to measure energy density must be an absolute temperature. That means that T = 0 at absolute zero and that water boils, for instance, at 100°C + 273° or 373°K. (K is for Kelvin, the name of the absolute temperature scale.) What it means for us is that we must add 273 to all measurements made in degrees Celcius in order to use them in the efficiency equation.

THE SECOND LAW AND EFFICIENCY OF HEAT ENGINES

The conversion of heat energy to mechanical energy proceeds with very low efficiency. The paddle wheel generator has shown that this takes place in spite of conserving energy, because of the Second Law of Thermodynamics. The Second Law is based on the fact that a temperature difference is necessary to make heat energy flow to do useful work. Since temperatures eventually equalize at any temperature above absolute zero, *it is never possible to change all heat energy into mechanical energy.* Some heat energy always remains.



The Second Law of Thermodynamics leads to an efficiency equation that can be written mathematically in terms of temperature difference.

Remember:

$$\text{Efficiency} = \frac{\text{energy output}}{\text{energy input}} \text{ or } \frac{\text{work done}}{\text{heat put in}}$$

According to the Second Law, we can write this as:

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1}$$

In this handout, all temperatures are measured on the absolute scale where $T_{abs} = {}^\circ C + 273$. The amount of work that can be done depends, therefore, on the temperature difference, $T_1 - T_2$, and not on their values. The *efficiency* will be greater, of course, for a given difference if T_1 is as small as possible.

The amount of work accomplished by a heat engine depends on the difference in temperature. This can be compared to a water wheel such as the one shown on page 56. The energy available to turn the wheel (in this case gravitational potential energy, not heat energy) depends on the difference between the height at the top of the wheel and at the bottom. The energy available and work done will be the same for the same difference in height whether the wheel is in an Alpine valley or on a New England stream.

Student Handout 7–6

Measuring Maximum Efficiencies of Heat Engines

A practical application of the conversion of heat to mechanical energy is the automobile engine.
T_1 = the temperature of the heat source.
T_2 = the temperature of the machine's surroundings.

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1} \times 100\%$$

which can also be written as:

$$\text{Efficiency} = 1 - \frac{T_2}{T_1} \times 100\%$$

1. Suppose the input temperature of the gas pushing the piston, T_1, is 4000°F (2204°C) and the temperature of the exhaust gas, T_2, is 1000°F (538°C).
   a. What would be the upper limit efficiency fixed by the Second Law?
   b. If automobile efficiencies are now on the order of 25 percent, is there much room for improvement?
2. Set up the steam turbine-generator combination and calculate its efficiency. The only piece of new equipment you will need is a °C thermometer that is calibrated to 150°C. T_1 is the temperature of the steam escaping the mouth of the steam generator. Hold the thermometer bulb in its path to measure it. T_2 is the room temperature. Find T_1 and T_2.
3. Calculate the Second Law efficiency of your turbine.
   a. How does the actual efficiency of the steam turbine-generator compare with the efficiency you calculated in question 1a?
   b. What is the major factor responsible for the difference between the two?

Lesson 8

How Automobile Engines Work

The mechanics and fuel needs of cars, the ever-present machines upon which we rely so heavily and which contribute so heavily to the energy problem, are the subject of this lesson. Students will examine some of the parts of the automobile engine, see how the engine works, define the properties of gasoline and diesel fuels, and compare gasoline and diesel automobiles.

OBJECTIVES

Students should be able to:

- Identify some of the parts of a car engine.
- Recognize differences between gasoline and diesel engines.
- Describe some properties of gasoline and diesel fuel.
- Explain the four-stroke cycle of gasoline engines.
- Recognize advantages and disadvantages of both gasoline and diesel-powered automobiles.

TARGET AUDIENCE

Students of General Science, Driver Education

TIME ALLOTMENT

Four to five class periods

MATERIALS

Student Handout 8–1, "Automobile Engines"
Student Handout 8–2, "What Are the Properties of Gasoline and Diesel Fuels?"
Student Handout 8–3, "How Do Gasoline and Diesel Engines Work?"
Student Handout 8–4, "Advantages and Disadvantages of Gasoline and Diesel Automobiles"

Activity 1
- Alcohol
- Motor oil
- Graduated cylinder (100 ml)
- Balance

Activity 3
- Bicycle tire
- Pump
- Test tube
- Balloon
- Test tube holder
- Bunsen burner or alcohol burner

Activity 1

The questions in this activity are not intended to cover the whole operation of the gasoline engine, but merely to introduce some of the parts of the engine and their relationship to energy use. Because every car engine is unique, you may want to compare several engines in different cars; or you may want just to deal with the engine in general terms.

Divide the class into groups of three to five students. Be sure that at least one person in each group knows (or thinks she/he knows) about car engines. Distribute Student Handout 8–1, "Automobile Engines" for groups to work on during part of the class period. When groups have completed the questions, go over the handout as a class to gain consensus.

The answers to the questions are given below, but don't hesitate to rely on your students' knowledge of cars (they often know as much or more than teachers on this subject).

Answers to Student Handout 8–1

1. To start the car.
2. To keep the engine cool.
3. Small, fuel-efficient.
4. One. Provide the spark to ignite the fuel. The engine uses more fuel.
5. Mixes the air and fuel.
6. Fuel injection systems.
7. It filters the air before it goes into the carburetor. The engine will consume more gasoline because the air-fuel mix will be wrong.
8. Gasoline, motor oil, brake fluid, transmission fluid, antifreeze. All of these. The engine could be damaged; friction will be increased.
9. Answers will vary. Some parts of the engine that students might mention include distributor cap, fan belt, generator, coil, and oil dipstick.
10. Similarities: Both have a radiator, generator, battery, cylinders. Differences: A diesel engine has glow plugs instead of spark plugs, an oil injection system (equivalent to fuel injection in some gasoline engines), a higher compression engine.

Next, if possible, take the class to a car (at an auto shop, or in the parking lot) and have them look under the hood for some of the parts described in the questions. Or, you may want to bring in some of these items (spark plug, air filter, carburetor, antifreeze, motor oil, etc.). Try to emphasize how the fuel is used in the engine and ways to maintain good gasoline mileage. Spend a little time discussing some of the major differences between gasoline-powered engines and diesel-powered engines.

Extending the Learning

Have students inspect their family cars and try to identify some of the engine parts discussed in this activity. Or students can compare the gasoline and diesel versions of automobiles that are otherwise identical. Students also can interview car dealers in order to compare gasoline and diesel engines.

Activity 2

Gasoline and diesel fuel are distilled from crude oil. Gasoline is a lighter component (fraction) of the distillation process. Diesel fuel is similar to home heating oil. Gasoline is typically classified on the basis of its octane rating, a measurement of the ratio of octane to other components. In diesel fuel, the cetane rating similarly classifies the quality of the fuel. The energy content of diesel fuel is about ten percent higher than gasoline. In addition, the energy expended to produce diesel fuel at the refinery is about half as much as that needed to produce gasoline. As an introduction to the experiment, present these definitions of fuel properties to the class.

1. *Ignition quality:* The ability of a fuel to ignite by itself in the engine cylinder.
2. *Heating value:* The average amount of heat that can be produced by burning a given quantity of the fuel.
3. *Volatility:* The ability of a liquid fuel to vaporize. The more volatile the liquid, the more likely it is to change into a vapor.
4. *Flash point:* The lowest temperature at which a liquid fuel will give off enough vapors to ignite in the presence of a flame. This is a measure of the safety of the liquid. Some states and insurance companies have regulations regarding flash points of fuels.
5. *Viscosity:* The ability of a liquid to flow. A viscous liquid is very difficult to pour, whereas a less viscous liquid is easily poured.
6. *Sulfur content:* The measure of the amount of sulfur in a given quantity of fuel. Sulfur is an impurity that causes air pollution. If a fuel has a high sulfur content, it will produce more harmful sulfur oxides as exhaust. In addition, the oxides of sulfur may corrode the cylinder walls of the engine.
7. *Density:* A measure of the mass (or weight) of a given volume. This is usually expressed in grams per milliliter.
8. *Color:* Fuels vary from almost clear to a very dark color. Examining the color of a fuel can help to determine its components.
9. *Odor:* The odors of fuels vary. The odor can be compared to the other properties of a fuel to try to develop a pattern.
10. *Boiling point:* The boiling point is an important safety consideration. If the boiling point is extremely low, the fuel could vaporize and develop an elevated pressure within a fuel tank.

Because it would be unsafe (and illegal in many schools) to use gasoline and diesel fuel in the lab, alcohol and motor oil are substituted for laboratory study in this activity. These two fuels are not meant to simulate gasoline and diesel fuel, but to provide illustrations of some important properties of liquid fuels.

One day before presenting this lab, place a beaker of alcohol and a beaker of motor oil in the freezer. (In this lab activity, students are asked to describe the viscosity of both cold and room temperature liquids.)

Divide the class into small groups. Distribute a set of materials to each group and a copy of Student Handout 8–2, "Determining Properties of Liquid Fuels." Students should follow the steps on the handout and complete the experiment. To conclude the activity, students should work individually on the properties chart and subsequent questions.

Answers to Student Handout 8–2

Data Chart: Data from lab work will vary.

1. The two liquids are about the same density.
2. Motor oil.
3. Motor oil.

	Gasoline	**Diesel**
Viscosity	low	high
Density	low	high
Color	light	dark
Odor	strong	strong
Boiling point	low	high

4. Diesel fuel.
5. Diesel fuel.
6. Gasoline; because it has a low flash point.
7. Diesel fuel; because its viscosity increases in cold temperatures.
8. Gasoline.
9. It pollutes the air. It may also damage engine parts.
10. Gasoline; because it is more volatile.

Extending the Learning

You may want to bring in small samples of gasoline and diesel fuel to demonstrate the properties listed on the chart. The fuels should be stored in safety containers. Try putting a small amount of diesel fuel in the freezer along with the alcohol and motor oil. Students will be able to see that the diesel fuel becomes more viscous in cold temperatures.

Activity 3

Background Information

All energy exists in either a potential (stored) or kinetic (active) state. Gasoline and diesel fuel contain potential chemical energy. When they are burned, their energy is transformed into heat, some of which can be converted to mechanical energy to run an automobile.

The way in which the fuel is burned in an engine's cylinder depends on many factors. These are outlined in Student Handout 8–3. If students understand the general properties of gases, they will understand how fuels give up energy in the four–stroke cycle of an automobile engine. As the temperature of a gas inside a closed container increases, its pressure increases as well. If the gas is compressed, the pressure and temperature will increase. The relationship that explains all of the factors is:

$PV= nRT$ where $P=$ pressure, $V=$ volume,
$n=$ number of moles of the gas,
$T=$ temperature, and $R=$ gas constant

Using the metric system, P would be measured in atmospheres, V in liters, T in degrees Kelvin, and n in moles. R would equal .082 1-atm/mole-°K.

Energy System Efficiency of the Automobile

Step	Efficiency of Step (%)	Cumulative Efficiency (%)
Crude Oil Production	96	96
Gasoline Refining	87	84
Gasoline Transportation	97	81
Thermal to Mechanical Energy Conversion (in engine)	25-30	20-24
Mechanical Efficiency of Transmission (includes auxiliary systems)	50-60	10-15
Rolling Efficiency	60	6-9

The engine cycle explained in this activity is that of a typical gasoline engine. The idea of fuel injection is not developed, nor are turbo charging and other modifications of the internal combustion engine. If this information is needed, refer to auto shop teachers or standard automotive references.

The performance of the engine is dependent on more factors than those listed in the Student Handout. The pollution control equipment on today's cars needs to be functioning properly for maximum performance. Also, the choice of gasoline may be crucial to maximum performance in some engines.

The concept of the efficiency of an automobile may come up in classroom discussions. The following chart will give you an idea of the system efficiency of the automobile.

Teaching Strategies

Distribute Student Handout 8–3, "How Do Gasoline and Diesel Engines Work?" and start the activity by discussing the basic introductory terms in Part I that have to do with gases.

Next, divide the class into small groups and have them do the two short experiments to experience temperature change related to a change in pressure or volume. (If not enough tires and pumps are available, you could do these experiments as a demonstration.)

Next, students should read Part II of the Handout. For an explanation of the four-stroke cycle, you may want to make some overhead transparencies. Develop this slowly; it is not always an easy concept for students to understand.

Answers to Student Handout 8–3

PART ONE

Experiment 1

1. Cooler.
2. Decreasing.
3. Warmer.
4. a) Decreases.
   b) Increases.

Experiment 2

4. It inflates.
7. It deflates.
8. a) Increases.
   b) Decreases.

PART TWO

1. It increases.
2. Gas.
3. Temperature and pressure both increase.
4. Temperature and volume both increase.
5. Through the exhaust system out into the atmosphere (air).
6. Intake stroke again.
7. Poor timing; dirty spark plugs; improper air-fuel mixture; worn cylinder walls causing compression loss; etc.

After your discussion of the four-stroke cycle, discuss the factors that affect engine performance. You may want students to try to come up with some ideas first, based on what they know about the engine.

Extending the Learning

There are several areas where the basic idea of the activity could be extended. If you would like to develop the gas laws, this is a complete unit in any chemistry course. If a demonstration cylinder is available to show a changing volume, this could better illustrate what actually happens in the engine cylinder than do the experiments in this activity.

Students could compare and contrast fuel-air mixing in a carburetor and a fuel injection system; or the four-stroke cycles of diesel, gasoline, and new high performance engines.

Activity 4

This is a consumer-related activity. A few of the 20 factors mentioned in Student Handout 8–4 need clarification.

The fact that some diesels are rated higher than gasoline engines is misleading. The safety of the fuel is not really an issue, since automobile manufacturers are required to follow strict safety standards in their fuel storage systems. The pollution factor is also quite misleading. The primary pollutants regulated by federal law are hydrocarbons (unburned fuel), carbon monoxide, sulfur oxides, and nitrogen oxides. The gasoline engine was the focus for the original federal pollution control standards. The diesel engine meets the federal standards for all of the pollutants right now. However, the nitrogen oxides produced by a diesel engine are quite high, and will be difficult to lower without the installation of equipment that reduces engine efficiency. Also, diesel fuel exhausts a much higher amount of particulates than does gasoline. Some preliminary research has shown that these particulates are potential carcinogens. The important point is that pollution from a diesel engine is not necessarily lower than that from a gasoline engine—it is different.

Distribute Student Handout 8–4, "Advantages and Disadvantages of Gasoline and Diesel Automobiles." Tell students to answer the questions in Part I before going ahead. There are no right answers to these questions, but they require an opinion that has not been influenced by the facts that follow. Students should list the seven factors they consider to be most important from the list given them. When they have completed the first part, students should study the chart and decide which of their important factors are better met by a gasoline, and which by a diesel engine. (Neither engine may assuage their concerns satisfactorily.) You may want to point out that on several factors the motorists apparently did not agree.

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Student Handout 8–1
Automobile Engines

1. What is the primary purpose of the battery?
2. Most cars have radiators. What is the purpose of the radiator?
3. Most cars have from four to eight cylinders. A four–cylinder engine would typically be found in what kind of car?
4. How many sparkplugs are there for each cylinder in an engine? What does a sparkplug do? What happens to fuel consumption when sparkplugs get old and dirty?
5. What does the carburetor do?
6. Some engines do not have carburetors. How do they accomplish the carburetor's task?
7. What does the air filter do? If the air filter is dirty, what will happen to gasoline consumption?
8. What are some of the fluids needed to keep a car going? How many of those fluids are petroleum based? What can happen to the engine if the motor oil is dirty or low?
9. List five other parts in a car engine and explain their functions.
10. Compare a gasoline engine with a diesel engine. What are some similarities? What are some differences?

Student Handout 8–2
Determining Some Properties of Liquid Fuel

In this experiment you will determine the color, odor, density, and viscosity of two liquid fuels—alcohol (methane) and motor oil. (Gasoline and diesel fuel are highly flammable, and are therefore unsafe to use in a school laboratory.)

PROCEDURE
1. Exercise caution when working in the laboratory.
2. Find the mass of your graduated cylinder and record it on the data chart.
3. Pour exactly 100 ml of alcohol into the cylinder. Find and record the mass of the cylinder with the alcohol in it.
4. Look at the alcohol. Record its color.
5. Smell the alcohol. Try to describe the odor. Record your description.
6. Repeat steps 2–5 for the motor oil.
7. Observe the viscosity of the two liquids. Remember that the viscosity of a liquid is its ability to flow easily. Although both liquids flow easily, try to determine if one flows more easily than the other. Record.
8. Your instructor has a beaker of each liquid that has been kept cold in the freezer overnight. Observe and record the viscosity of the cold liquids.

After you have completed the experiment and recorded all observations, do the calculations and answer the questions.

QUESTIONS
1. Which liquid is more dense?
2. Which liquid is darker?
3. Which liquid is more viscous?

Data Chart

	Alcohol	**Motor Oil**
1. Mass of empty cylinder		
2. Mass of cylinder + liquid		
3. Density = mass/volume		
4. Color		
5. Odor		
6. Viscosity (room temp.)		
7. Viscosity (cold)		

$$\text{Calculation: Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$= \frac{\text{Mass of the liquid alone in grams}}{\text{Volume of liquid used (100 ml)}}$$

If you would compare gasoline and diesel fuel, you would find that diesel fuel is denser, darker, and more viscous than gasoline. In addition, diesel fuel boils at a higher temperature than gasoline.

Gasoline and diesel fuel both come from crude oil production. When the oil comes out of the ground, it is usually very dark and thick. In the refinery, the oil is separated into its various fractions. Some of the products that come from crude oil are lubricating oil, home heating oil, tars, petroleum jelly, plastics, kerosene, jet fuel, and asphalt, as well as diesel fuel and gasoline.

Gasoline and diesel fuel are separated (refined) by distillation, a process that requires energy. It takes roughly twice as much energy to distill gasoline as to distill diesel fuel. Of the total production of crude oil, 50 percent is distilled into gasoline, while only 10 percent is distilled into diesel fuel.

Based on the experiment and the reading above, complete the following chart. Then use it to answer the questions that follow.

	Gasoline	**Diesel**
Viscosity		
Density		
Color		
Odor		
Boiling point		

4. Which of the two fuels has the highest heat value?
5. A tankful of which fuel would be able to provide the most energy?
6. Which of the fuels do you think would have the greatest safety problems? Why?
7. With which fuel would you expect to have the greatest difficulty during the winter? Why?
8. Which of the fuels will need a spark plug to start the ignition process?
9. What is the problem with a high sulfur content in a fuel?
10. Which of the fuels would you be able to smell first if a jar of each were opened in the front of the room and you were in the back? Why?

Student Handout 8–3

How do Gasoline and Diesel Engines Work?

I. TEMPERATURE, VOLUME, AND PRESSURE

We all know that we can drive into a gas station, fill up the tank, and drive off again. Without even thinking, we get into the car, turn the key, and away we go. But stop for a second and think about it. You go to a gas station and get a liquid fuel, and by some miracle of technology, the liquid is transformed into energy to propel the car down the road.

How is this done? This activity will try to unravel the mystery of the automobile engine. Look first at these terms that will be used in discussing the operation of an engine:

Pressure: When molecules of gas move around in a container, they tend to collide with the walls of the container, as well as with each other. Pressure is a result of the force and energy of the molecular collisions that occur in the container.

Volume: The amount of space that a container encloses.

Temperature: Although we measure temperature with a thermometer and it tells us how "hot" something is, the technical definition of temperature is the average speed of the molecules in a container. The faster the molecules are moving, the higher the temperature, and the higher the average kinetic energy of the molecules.

Combustion: This is the burning of substances. In automobiles, combustion takes place in the engine, and they are called "internal combustion engines."

Experiment 1: How are Pressure and Temperature Related?
PROCEDURE

1. Deflate the bicycle tire. Feel the tire as it is deflating. Does it seem to be getting cooler or warmer?
2. As you are deflating the tire, is the pressure increasing or decreasing?
3. Now attach the pump to the tire and inflate the tire rapidly. Is the tire getting warmer or cooler?
4. Complete the following statements about the relationship between pressure of a gas and the temperature.
   a) As pressure decreases, temperature __________.
   b) As pressure increases, temperature __________.

Experiment 2: How are Temperature and Volume Related?
PROCEDURE

1. Place the balloon over the end of the test tube.
2. Put on your safety goggles.
3. Using the test tube holder, place the test tube in the flame.
4. What happens to the balloon as the test tube is heated?
5. After heating for about three minutes, remove the test tube from the flame.
6. Place the test tube under cold running water.
7. What happens to the balloon as the test tube is being cooled?
8. Complete the following statements about the relationship between volume and temperature:
   a) As temperature increases, volume __________.
   b) As temperature decreases, volume __________.

II. THE FOUR-STROKE AUTOMOTIVE CYCLE

An engine is any machine that is operated to produce mechanical energy, the energy to make things move. The automotive engine produces mechanical energy by burning a fuel inside the engine. That is why it is called an *internal combustion engine.*

The typical gasoline or diesel engine in a car is a four-stroke operation. The four strokes take place in each one of the cylinders. Cars may have four, six, eight, or twelve cylinders, depending on the power of the engine and the size of the car.

A cylinder is a metal container that is long and round like a pipe. It has one open and one closed end. The piston is placed in the open end of the cylinder, fitting very tightly. As the piston moves up and down in the cylinder, the crankshaft is turned. When the crankshaft—which is attached through gears to the wheels—turns, the car moves down the road.

But the big question is: What makes the piston move up and down?

To answer this question, refer to a physical science textbook for a diagram of a four-stroke engine. Note the four-stroke cycle of a piston: intake, compression, power, and exhaust. After you have studied the diagram, answer the following questions.

QUESTIONS

1. What happens to the volume of gas in the cylinder?
2. In what state of matter is the gasoline when it enters the cylinder?
3. As the valve closes, what happens to the temperature?
   a) increases b) decreases c) stays the same
4. When the gasoline/air mixture is burned, it produces heat. Then what happens to the volume?
5. Where do the burned gases go when they leave the cylinder?
6. What step follows the exhaust stroke?
7. Look back at the four-stroke cycle. List some conditions that might affect the efficiency of the engine.

A diesel engine is also a four-stroke engine, but there are some differences between the diesel and the gasoline engine. For example, a diesel engine has no spark plugs. Instead, the fuel is ignited by the high temperature in the cylinder. There are other differences as well. You may want to research the four-stroke diesel engine now that you know about the gasoline engine.

Student Handout 8-1

Advantages and Disadvantages of Gasoline and Diesel Automobiles

PART ONE

Suppose you were in the market for a new car. You would want to make an intelligent choice because it is expensive to buy, fuel, and repair an automobile. Below is a list of factors you should consider when deciding between a gasoline and a diesel powered car.

Original cost of automobile
Warm weather starting
Cold weather starting
Acceleration and responsiveness
Smoothness of ride
Pollution
Fuel cost per mile
Availability of fuel
Miles per gallon
Safety from fuel fires
Cost of repairs
Availability of parts
Frequency of engine breakdowns
Cost of repairs
Engine life
Do-it-yourself maintenance
Do-it-yourself repairs
Amount of routine service
Cost of routine service
Availability of good mechanics

From the above list of 20 factors, pick the seven that *you* would consider to be the most important in choosing a new car. Think carefully about all of the factors before writing down your seven choices.

PART TWO

The chart shows the results of a survey given to motorists about gasoline- and diesel-powered cars. Based on the chart, decide whether you would rather buy a car with a gasoline or a diesel engine.

Motorists' Opinion of Diesel- and Gasoline-Powered Automobiles

Characteristic	Diesels Definitely or Generally Better	About the Same	Gasoline Definitely or Generally Better	Don't Know
Diesels Rated Better				
Fuel cost per mile	80%	9%	5%	6%
Miles per gallon	64	20	8	8
Engine life	59	27	6	8
Safety from fuel fires	54	35	4	7
Frequency of engine breakdowns	48	39	5	8
Cost of repairs	43	41	8	8
Pollution	35	28	29	8
Diesels and Gasoline About the Same				
Warm-weather starting	20%	58%	14%	8%
Smoothness of ride	13	58	19	9
Do-it-yourself maintenance	8	47	37	8
Do-it-yourself repairs	6	46	40	8
Amount of routine service	41	41	10	8
Cost of routine service	35	35	22	8
Gasoline Rated Better				
Availability of qualified mechanics	2%	18%	72%	8%
Original cost of automobile	9	18	65	8
Availability of parts	2	28	61	9
Availability of fuel	12	23	58	7
Cold-weather starting	15	29	48	8
Acceleration and responsiveness	11	35	45	9
Cost of repairs	15	38	39	8

Check each of the factors you listed to see if diesel or gasoline engines rated better, or if they rated about the same. Write the result next to each factor on your list.

According to your own rating, would you be a potential diesel-powered automobile owner, a gasoline-powered automobile owner, or both? What other factors that are not listed would you want to consider in buying a new car?

	Gasoline	**Diesel Fuel**
Ignition quality	Has a relatively low ignition quality, meaning the gasoline needs a spark to ignite.	Will self-ignite at a relatively low temperature. The best diesel fuels have a high ignition quality.
Heating value	approx. 124,000 Btu/gallon	approx. 143,000 Btu/gallon
Volatility	Extremely volatile	Slightly volatile in comparison
Flash point	Relatively low temperature	Slightly higher than gasoline
Viscosity (high or low)	Low	High
Sulfur content	The sulfur content of fuels varies depending on the sulfur contained in the crude oil. In addition, refinery processes can remove some of the sulfur. The content will vary greatly.	
Density (high or low)	Low	High
Color (dark or light)	Light	Dark
Odor (strong or weak)	Strong	Strong
Boiling point (high or low)	Low	High

Lesson 9

New Inventions and Improvements

After sitting in gas lines in 1974 and 1979 and paying more than they ever could have imagined for a gallon of gasoline, Americans have become concerned about the future of the automobile. One goal of this lesson is to look at what is being done in automobile-related industries to make this mode of transportation more efficient and less dependent on foreign oil. Future fuels, improvements in auto design, and the state of research and development of alternative automobiles are presented.

OBJECTIVES

Students should be able to:

- Identify future alternative fuels and how they can be used.
- State several ways the conventional automobile is becoming more efficient.
- Describe short- and long-term developments for the automobile.

TARGET AUDIENCE

Students of General Science, Environmental Science

TIME ALLOTMENT

Three to five class periods

MATERIALS

Student Handout 9–1, "Fuels of the Future"
Student Handout 9–2, "Improving What We Drive"

Activity 1

To begin this lesson, ask: What can be used as fuel in an automobile other than gasoline? List class suggestions on the board. What is the source of each fuel? Do you think these fuels could be distributed as widely and easily as gasoline?

Next, distribute Student Handout 9–1, "Fuels of the Future." Compare students' brainstormed ideas with the gasoline alternatives listed in the chart. Then discuss the chart with the class.

The questions that follow the chart can be used to evaluate student performance or assess class discussion.

Answers to Student Handout 9–1

1. These fuels are made from domestic resources and are not petroleum-based.
2. The market value of grain, the energy costs of its production, and indirect costs, especially the trade-off in land use between food crops and fuel crops.
3. Organic waste products (garbage, crop, and industrial residues) can be used to produce methanol, thus reducing environmental impacts and making useful a "worthless" resource.
4. Because of its short range, an electric car is best suited for short trips. It is also non-polluting, making it an excellent choice for urban transport (taxis, delivery vehicles, etc.).
5. Hydrogen. It is the most abundant element on earth. It can be produced by separating water into hydrogen and oxygen. When hydrogen is burned, water is produced.
6. Ethanol and methanol. The source of the fuels continues to be grown (plants) or made (waste)—making and using the fuel does not exhaust the resource.
7. Ethanol and to some extent, methanol. Both can be used in existing combustion engines as "gasohol," a 90/10 mixture of gasoline and alcohol.
8. Batteries, hydrogen.
9. Hydrogen. Water is cheap, but the conversion technology is currently very costly.
10. Advantages: they replace oil used to fuel transportation; they pollute less than gasoline. Disadvantages: answers will vary.

Extending the Learning

Assign extra credit reports on research and development of these fuels. Or, students could research other new fuels (i.e., steam, propane). They could add these new fuels to the chart.

Activity 2

Distribute Student Handout 9–2, "Improving What We Drive." Explain that the automobile industry is trying to improve the automobile as we know it. Discuss each item of the handout with the class, or assign individual or group reports on specific developments. Encourage students to call or write a major automobile manufacturing representative in your area or in Detroit for information.

Students should make up their own techniques by which to incorporate any or all of the efficiency options noted on the handout. They should draw a picture of a car with their improvements, label the modifications, and present their car of the future to the class. A bulletin board display also could be arranged. Students who do not want to draw can make a rough sketch or a model to illustrate their improved design. (In Detroit, design ideas often are rendered in clay.)

Call a major automobile manufacturer in your area and request a speaker from their public relations department for your class. If speakers are not available, ask for films or other materials about their efforts to make their vehicles more energy-efficient.

Student Handout 9–1
Fuels of the Future

Fuels of the Future

Fuel Alternative:	**Ethanol.**
Fuel Source:	Plants: grains, sugar cane, sugar beets, and other sugar sources (produced by fermentation).
Advantages:	Can be used for fuel as produced or mixed with gasoline. A 10 percent ethanol, 90 percent gasoline mixture is marketed as "gasohol" and can be used in gasoline engines. Alcohol increases the octane rating, reduces carbon monoxide emissions, and makes lead additives unnecessary.
Disadvantages:	Must be water-free if mixed with gasoline. Engine modification is necessary if used as produced or in its hydrous (water-containing) form. Ethanol has lower energy density than gasoline so there is a decrease in MPG. The major disadvantage of the production of ethanol from grains is that it increases the demand for grains and competes with food crops for growing space, both of which could increase food costs.
State of the Technology:	Ethanol is now produced by both small and large distilleries. Without a tax incentive, gasohol cannot compete economically with gasoline. If it must be distilled to remove water, more energy would be used to manufacture it than is contained in the fuel. New production technologies may improve this ratio. For a small-scale farm producer who uses wood and solar energy to distill the ethanol, the production of this fuel is economically feasible.

Fuel Alternative:	**Methanol.**
Fuel Source:	Natural gas, coal, wood waste, organic waste.
Advantages:	Same as ethanol. Methanol production does not compete with food crops. Energy resource is large if methanol is made from coal and wood.
Disadvantages:	No economically competitive conversion process exists. Engine modification is required. Engines fueled by methanol start poorly at low temperatures. Methanol has lower energy density than gasoline.
State of the Technology:	Efforts continue to develop economical large-scale production of methanol from coal and wood.

Fuel Alternative:	**Electricity.**
Fuel Source:	Any source of electricity (coal, oil, water, geothermal, solar, nuclear) can be used to charge a battery. Or a fuel cell can be used as the power source. Fuel cells run on hydrogen or, in conjunction with a reformer, on any hydrocarbon. A reformer makes a hydrogen-rich gas out of a hydrocarbon fuel.
Advantages:	Electrical motors driven either by batteries or fuel cells would be quiet and non-polluting. Resources for electrical generation are large. Recharging could be done at night when utility loads are smaller.
Disadvantages:	Current battery-powered electric vehicles have limited power and range. Fuel cells are not yet economically competitive.
State of the Technology:	New batteries made of lighter materials and with better acceleration and endurance are under development. Fuel cells are still too expensive, but mass production should lower cost. Both may be available in the late 1980's or 1990's.

Fuel Alternative:	**Hydrogen.**
Fuel Source:	Any hydrocarbon; however, the largest source is water (H_2O).
Advantages:	Large resource available; non-polluting combustion (water is the combustion product); high energy value.
Disadvantages:	Storage is difficult because this lightweight gas must be compressed, liquefied, or absorbed as metal hydrides. For hydrogen to be an economical fuel, either a cheap source of electricity must be found to produce hydrogen from water using electrolysis; or some other inexpensive process for separating hydrogen from water must be developed. Hydrogen is explosive (but is probably no more dangerous than gasoline).
State of the Technology:	Hydrogen production is still a fledgling process and it is very expensive.

QUESTIONS

1. How can increased ethanol and/or methanol production help reduce U.S. dependence on foreign oil?
2. What cost factors must be considered in the production of ethanol?
3. What is an environmental benefit of methanol production?
4. Where might an electric automobile be most useful?
5. Which fuel alternative for vehicles has an almost limitless source of energy?
6. Which fuel alternatives listed on the chart are made from renewable sources? What makes the sources renewable?
7. Which of the new fuel alternatives are currently available for public consumption?
8. Which new fuel alternatives still need to be perfected?
9. Which fuel alternative is currently the least cost effective for transportation needs?
10. What advantages do all these alternatives share? List one disadvantage for each fuel.

Student Handout 9–2
Improving What We Drive

Because of the energy situation in general, our dependence on oil in particular, and the efficiency and performance standards set by the government, automobile manufacturers are working to improve the efficiency of their product. The industry is developing improvements in many areas including:

- Smaller supercharged or turbocharged engines to give immediate power.
- Lighter bodies.
- Body design to reduce aerodynamic drag.
- Ventilation systems and radial (instead of bias ply) tires to reduce drag.
- High quality oils, oil filters, and synthetic oils to reduce internal friction.
- Lighter metals for accessories (e.g. air conditioning) to reduce engine load.

Based on these concepts, your assignment is to design an automobile, improving on its efficiency in any of the ways listed above (or develop your own efficiency ideas). Label and identify all modifications made.

Lesson 10

Nuclear Power Plants: Design and Operation

The process by which electricity is made in nuclear power plants and the technology that makes it possible are described and demonstrated in this lesson. The effect of the First and Second Laws of Thermodynamics, levied against all heat-to-mechanical energy conversions, applies to nuclear plants as well. A nuclear power plant is a steam engine, whose ideal efficiency is limited by the Second Law of Thermodynamics.

OBJECTIVES

Students should be able to:

- Label the major components of a boiling water reactor (BWR) and a pressurized water reactor (PWR), describe the process of making electricity in these reactors, and point out the differences between them.
- Explain the function of major components in a BWR and in a PWR.
- Describe the energy transformations in a nuclear power plant.
- List four reasons why the actual operating efficiency of a nuclear power plant is less than the ideal operating efficiency.
- Discuss three ways waste heat can be dissipated in nuclear power plants.

TARGET AUDIENCE

Students of Chemistry, Physics, Physical Science

TIME ALLOTMENT

Three to four class periods

MATERIALS

Student Handout 10-1, "How Nuclear Power Plants Work"
Student Handout 10-2, "The Thermodynamics of Nuclear Power Plants"

Activity 1
Three heavy steel balls, suspended as pendulums (two of one size, one smaller)
String or monofilament
Support rod
Clamps
Stand
Two hockey pucks
Curved track

Activity 2
Hero's engine
Water
Bunsen burner
Thread
Support rod
Clamp
Stand

TEACHING STRATEGIES

It would be possible to use these readings and questions for a learning station on the mechanics of nuclear power. Students could do the demonstrations independently as well, *except* Hero's Engine (Activity 2) *which is too dangerous for unsupervised work.* Or you can ask students to read Student Handout 10-1, "How Nuclear Power Plants Work," and complete the checkpoint questions as a class.

Answers to Student Handout 10-1

Checkpoint A
1. D
2. C
3. E
4. B
5. A

Checkpoint B
1. Nuclear potential energy
2. Kinetic energy of fission products
3. Heat
4. Mechanical kinetic energy
5. Electrical energy

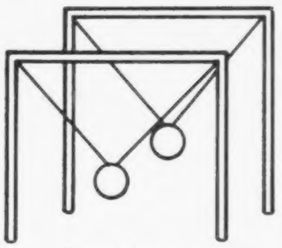
Checkpoint C
1. Containment structure, pressure vessel, core (fuel rods, control rods, moderator), steam lines, turbine/generator, condenser.
2. Secondary heat exchange loop in PWR, steam generator separate from core in PWR, cooling system.
3. In a PWR, steam to run the turbine is generated indirectly from the fuel through a secondary heat exchange loop, rather than directly from the core as in the BWR.
4. Answers will vary. Possible responses include: coolant does not come in contact with the core, so the turbine does not become contaminated (radioactive); more efficient heat transfer because pressure is higher; higher ideal efficiency.

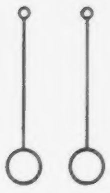
Activity 1

One steel ball striking another of the same size can be compared to a neutron striking a hydrogen nucleus: from an angle of approach the neutron will lose the greatest proportion of its energy in striking a particle of about equal mass.

Show how a moderator functions in slowing down fast neutrons by suspending two steel ball pendulums of equal size as shown.

Let a student hold one string and let another set one pendulum in motion, causing one steel ball to strike another. Substitute a smaller steel ball for one pendulum and repeat the process. (A bifilar suspension will limit the motion to one direction. If you wish to allow two-dimensional movement, use a monofilar suspension.) Ask: Does the small ball rebound as fast as the



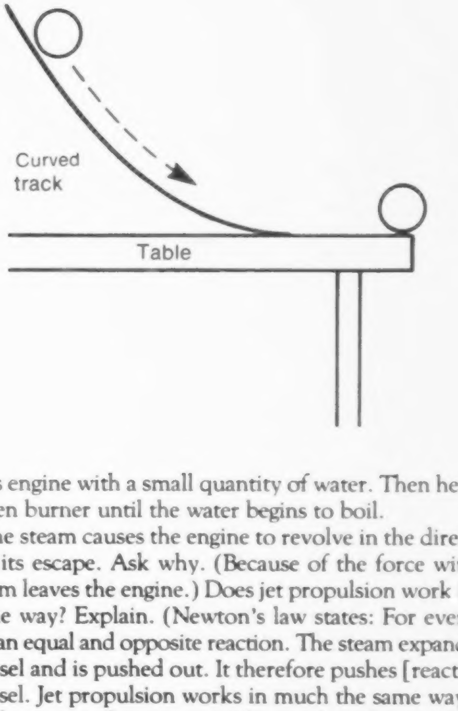


larger one? What can we learn from this? (Student answers will vary. Point out the need for using substances low on the periodic table, such as hydrogen, deuterium, and carbon as moderators so that captured neutrons will give up most of their energy.)

Demonstrate the principle again by making two objects collide. Use hockey pucks on a smooth surface or allow one ball to collide with a second ball at rest at the bottom of a curved track.

Activity 2

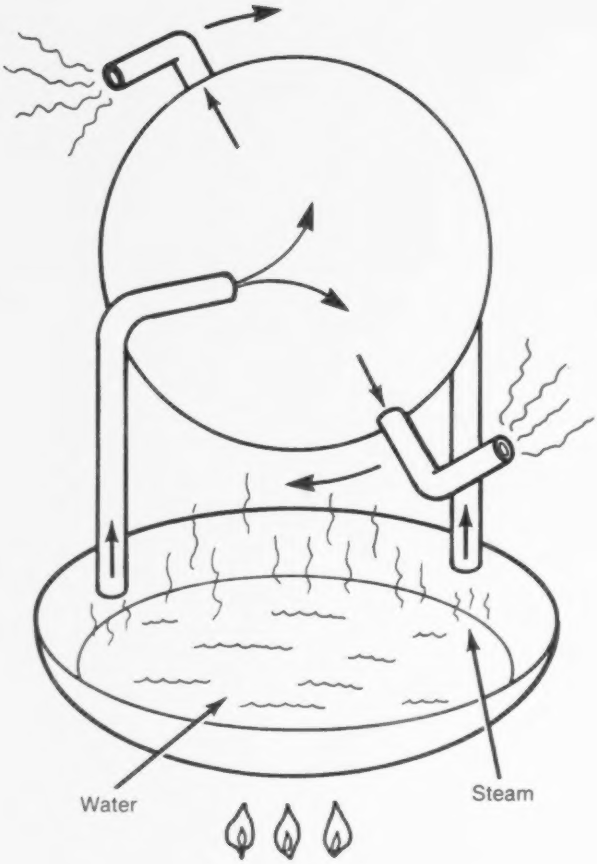
Demonstrate the conversion of heat energy to mechanical energy with Hero's Engine, believed to be the first steam engine. This engine is relatively inexpensive and is available from most supply houses.



Fill the glass engine with a small quantity of water. Then heat it over a Bunsen burner until the water begins to boil.

Note that the steam causes the engine to revolve in the direction opposite its escape. Ask why. (Because of the force with which the steam leaves the engine.) Does jet propulsion work in much the same way? Explain. (Newton's law states: For every action there is an equal and opposite reaction. The steam expands against the vessel and is pushed out. It therefore pushes [reacts] against the vessel. Jet propulsion works in much the same way. In a turbine, however, the steam pushes against the turbine blades and drives them *in the direction of the steam.*) What energy conversion has occurred? (Heat energy converts to mechanical [rotational] kinetic energy.)

You can construct a Hero's Engine in the following way. Obtain a rectangular metal can, such as an empty one-gallon duplicating fluid can. Punch a hole (with a nail) near the top right-hand corner of the largest side. Do the same on the opposite side.



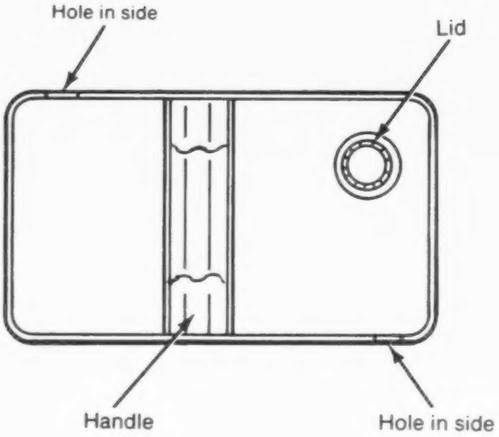
Caution: Beware of the dangers of using a heat generating system near students.

Put an inch or two of water into the can. Close the lid tightly and suspend the can by a string over the Bunsen burner. Heat the water. The can should rotate.

Ask students which alternative best completes this statement: In the Hero's Engine, the sphere rotates because the heat energy in the steam

a. warms the sphere.
b. rises into the sphere.
c. causes the steam to contract and draw air into the sphere.
d. causes the steam to expand and be propelled through the two outlets.
e. increases as the steam rises.

Distribute Student Handout 10-2, "The Thermodynamics of Nuclear Power Plants." Discuss the diagrams in detail. Help students determine the operating efficiencies of nuclear and coal-fired power plants.



Caution: Duplicating fluid is highly flammable. Be sure the can is clean before using.

Answers to Student Handout 10-2

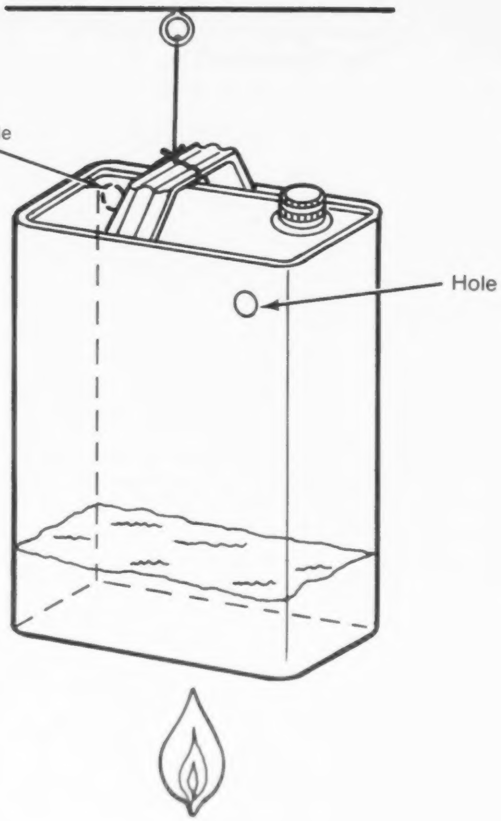
1. Nuclear (BWR): $T_1 = 563$, $T_2 = 311$
   Nuclear (PWR): $T_1 = 598$, $T_2 = 311$
   Coal (new): $T_1 = 811$, $T_2 = 311$
2. Nuclear (BWR): 45%
   Nuclear (PWR): 48%
   Coal (new): 62%
3. The cooling water must be brought in as a liquid. Therefore, T_1 cannot be 0° C (273° K).
4. Power plants are slightly more efficient in winter because the cooling water comes in at a lower temperature than in the summer.
5. Generally speaking, power plants must be designed so that they are safe under high operating pressures. This places an upper limit on the operating temperature.

Activity 3

To conclude the lesson, this pendulum demonstrates the laws that govern all energy conversions: the First and Second Laws of Thermodynamics.

Suspend a steel ball from a support by a string. Let the ball swing back and forth as a pendulum does. Ask these questions:

1. What energy conversions are taking place? (Gravitational potential energy to kinetic energy, back to potential energy.)
2. Does the total energy in the system remain constant?
3. What happens after a few swings? (The system is losing energy.) Why? (Air resistance and friction cause the conversion of mechanical energy to heat within the surrounding environment.)
4. Can you explain this in terms of the Second Law of Thermodynamics? (Any energy transfer or conversion of energy is irreversible; some of the energy is changed to heat and cannot be reconverted to a more useful form.)



5. Can you apply the principle of the pendulum demonstration to the operation of a heat engine? (No heat engine operating in a cycle can convert all of a given amount of heat energy to mechanical energy. Therefore, no heat engine can be 100 percent efficient.)
6. Can you apply the Second Law to a nuclear reactor? (Again, a significant amount of heat loses its usefulness in the mechanical energy conversion, and heat is discharged to the atmosphere. Heat is also lost through accidental leaks and through friction of moving parts—both convert some of the mechanical energy to useless heat.)

SOURCES

Dorf, Richard C. *Energy, Resources, and Policy.* Addison-Wesley, Reading, MA, 1978.

Fowler, John M. *Energy & the Environment,* 2nd ed. McGraw-Hill, 1984 (Chap. 11 and Appendixes).

Roeder, John L. "Throwing Dice in the Classroom." *The Physics Teacher* 15, 428 (1977).

Student Handout 10–1

Nuclear Power Plants: Design and Operation

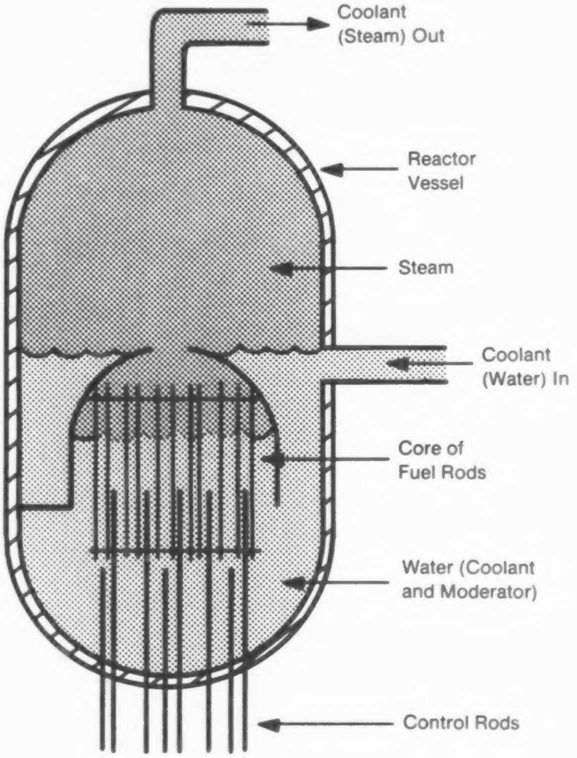
The production of electricity at a nuclear power plant requires four energy conversions. The first takes place when the fissioning nucleus splits and fission products fly off with considerable energy, thus converting nuclear potential energy to kinetic energy. When these fission products are slowed down by collisions with the remaining nuclear material, their kinetic energy is converted into heat energy. This second energy conversion occurs within the fuel rods. In the third conversion, the heat energy from the fuel rods is converted to mechanical energy. This mechanical kinetic energy is converted by the turbine-generator to electrical power.

What makes nuclear power unique is the use of fission to generate steam within the reactor. Part I of this handout concerns the components inside the reactor vessel that make possible the conversion of the kinetic energy of fission to the heat energy of steam. Part II covers the whole reactor (heat engine) system. Part III compares two reactor systems, the boiling water and pressurized water reactors.

PART I: COMPONENTS OF A LIGHT WATER REACTOR (LWR)

Reactor Core: The fuel consists of pellets of uranium dioxide (UO_2) contained in a series of fuel rods. Each rod is about 1.3 cm in diameter and 3.6 m long. The fuel is contained inside a "cladding," a tube constructed of non-corrosive, light, strong metal such as a zirconium alloy. The cladding protects and confines the fuel. The fuel rods are arranged in separate bundles ("fuel assemblies") of 80 to 100 rods. Depending on the size of the reactor, the reactor core may contain as many as 700 assemblies.

LWR Reactor Components



Coolant: In a light water reactor, the water surrounding the fuel rods serves a dual purpose. It acts as a moderator by slowing down the fast neutrons produced by fission to the "thermal" energy at which their probability of capture by $^{235}_{92}$ U (causing another molecule to fission) is very high. (See next section.) In addition the water cools down the fuel rods. The fuel rods get very hot from the release of fission energy within the rods. The centers of the rods reach temperatures of about 1050°C. They would melt quickly if circulating water did not remove the heat energy. This circulating water is also the means by which the energy is retrieved from the fuel and carried to the turbine for the next step in the conversion process.

The coolant does not touch the fuel itself. The cladding prevents most leakage. However, because of the extreme operating conditions, the coolant is contaminated by leakage of small amounts of radioactive material.

The most serious safety concern in operating a nuclear power plant is the possibility of an accidental loss of coolant. In such an accident, the system delivering the coolant to the reactor would malfunction, causing the reactor to overheat unless emergency cooling were provided. Reactors have several back-up systems to prevent this.

Can a nuclear explosion occur in the reactor itself? The answer is no. In order to explode like an atomic bomb, the uranium would have to be enriched to the point where it contains at least 20 percent ^{235}U and less than 80 percent ^{238}U. Reactor fuel contained about 97 percent ^{238}U that captures neutrons without fissioning. Because of its composition, the fuel can capture most of the extra neutrons released by the fissioning ^{235}U, thus preventing an explosion.

Moderator: For a chain reaction to proceed, the neutrons released by fission must be slowed so they can be captured by other nuclei of ^{235}U. Water provides the necessary delaying action. When neutrons strike protons of hydrogen, this causes the neutrons to lose about half their energy and speed. This ability to slow down neutrons makes water a good moderator. Light water reactors use ordinary water.

The United States uses light water reactors almost exclusively. However, the Canadian reactor (Candu) uses heavy water as a moderator, and the high temperature gas reactor uses graphite to slow down neutrons.

Control Rods: It is necessary to control the rate of a chain reaction. Boron and cadmium can absorb neutrons in order to decrease the number available for a chain reaction or even to stop the reaction. Control rods of these elements can be inserted into or retracted from the reactor core. The number that are inserted determines the neutron level and therefore the power level at which the reactor operates.

It is possible to stop the chain reaction by adding boron in the form of boric acid to the cooling water circulating in the reactor. Most reactors have both of these control and safety features.

Reactor Vessel: All of these components are enclosed in a steel vessel with walls about a foot thick. Then the reactor is surrounded by a leakproof containment vessel consisting of four or five feet of steel-reinforced concrete to halt any radioactive release to the environment. The reactor building itself often serves as a containment vessel.

CHECKPOINT A

Listed below are descriptions of the functions of the major components of an LWR. Match the reactor component with its correct description.

LWR Components

A. coolant (water)
B. control rods
C. ^{238}U
D. ^{235}U
E. moderator (water)

_____ 1. This isotope comprises about 3 percent of the uranium contained in the fuel rods. It serves as the energy source by capturing slow (thermal) neutrons and undergoing fission.

_____ 2. About 97 percent of the uranium present in the rods consists of this isotope. Its nuclei absorb most of the extra neutrons without undergoing fission themselves.

_____ 3. Collisions with the molecules of this substance slow the neutrons down. This slowing facilitates neutron capture by ^{235}U nuclei and thus helps maintain the chain reaction.

_____ 4. This component serves to absorb neutrons and regulate the power level at which the reactor operates.

_____ 5. This component prevents the fuel rods from melting. In addition, it provides the means by which heat energy is retrieved from the reactor.

PART II: CONVERTING HEAT ENERGY TO MECHANICAL ENERGY

In a nuclear power plant, the major components of the steam engine cycle are the reactor, turbine, condenser, and pump. The steam turbine is an external combustion heat engine in which the working fluid is steam.

Boilers in a fossil fuel power plant have the same function as the reactor in a nuclear power plant. Both make steam.

There are two kinds of light water nuclear power plants: boiling water reactors (BWR) and pressurized water reactors (PWR). The following description refers to the BWR.

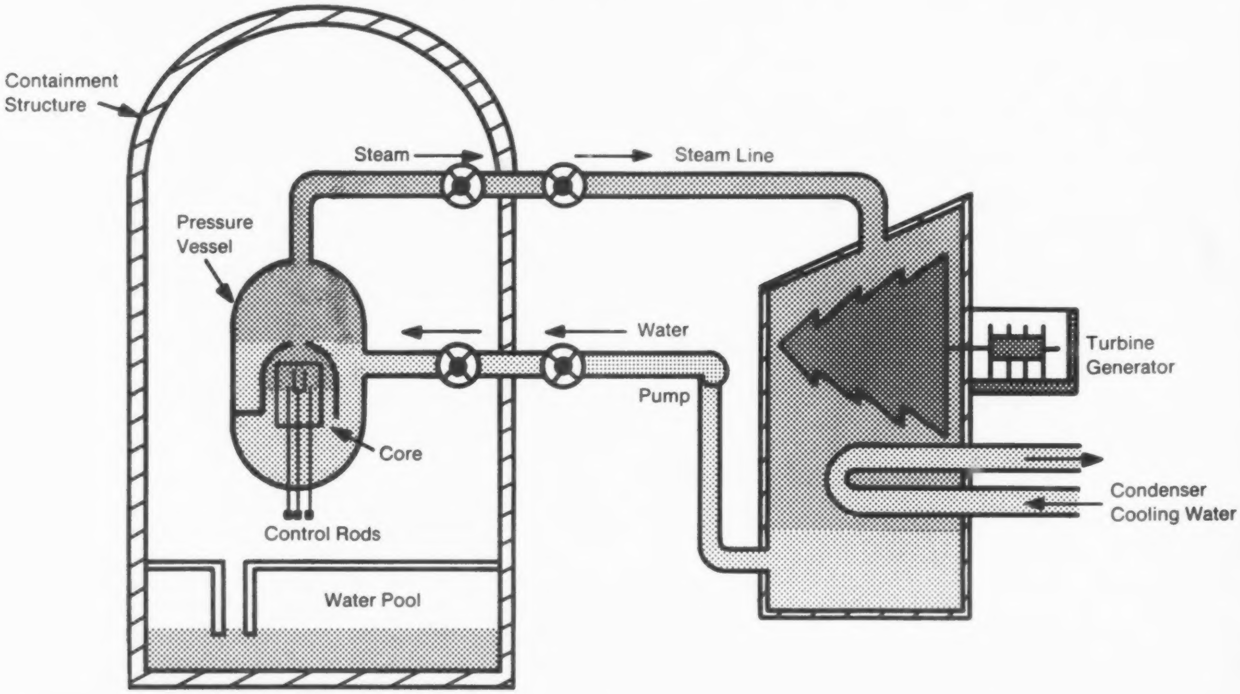
BOILING WATER REACTORS

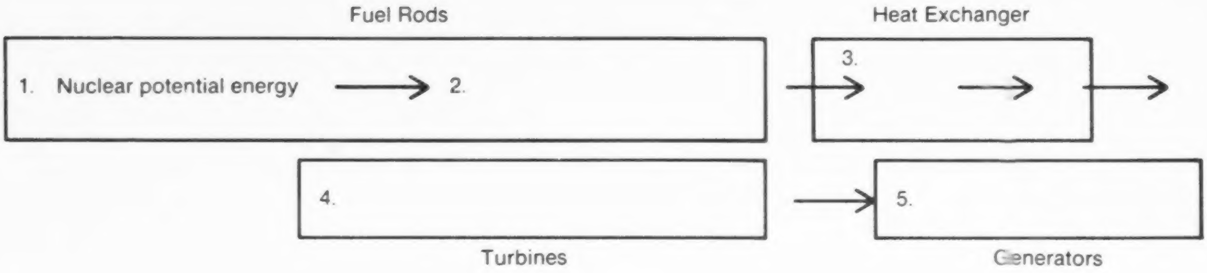
The term Boiling Water Reactor (BWR) refers to all the components of the power plant. The drawing shows a schematic diagram of a BWR including the reactor itself, where the actual energy release takes place.

Reactor. In the steam engine cycle the reactor is the source of heat energy which drives the engine. Coolant (water) leaves the condenser at a temperature of about 38°C and enters the reactor. It comes out of the reactor as pressurized steam at temperatures as high as 290°C and a pressure of 7×10^5km/m^2.

Turbines. Steam is under high pressure as it leaves the reactor. As the steam is expanded through the turbines, it strikes the blades to rotate the turbine. As the steam expands against the

Boiling Water Reactor

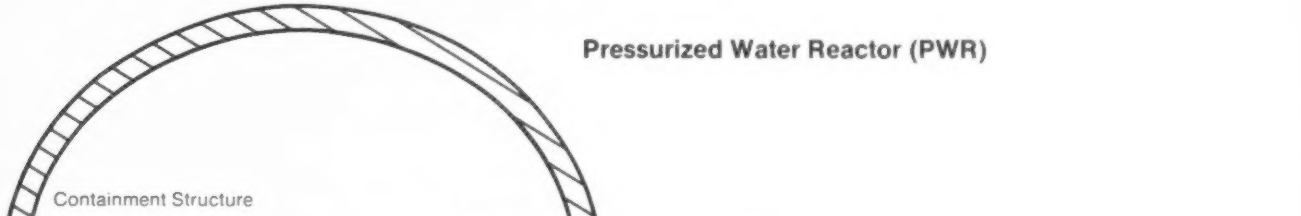



Fuel Rods
Heat Exchanger
1. Nuclear potential energy
2.
3.
4.
5.
Turbines
Generators

blades it drops in pressure and cools off. Steam working on the turbines converts heat energy to mechanical energy.

Condenser. Look carefully at the diagram. After it leaves the turbine, steam is passed through a condenser. Here it is cooled, condensed back to water, and pumped back to the reactor. In the process of recycling through the reactor the water again picks up heat energy from the hot reactor core, which produces steam again, and so on.

The condenser contains a series of coils through which water from a large nearby source—a natural lake, constructed lake, river, or bay—circulates. As steam passes over these coils (pipes), it cools and condenses to water. The circulating cooling water becomes hot from the steam. The heat is returned either to the donating body of water if "once-through" cooling is



Pressurized Water Reactor (PWR)

Containment Structure
Steam
Steam Line
Steam Generator
Control Rods
Pressure Vessel
Turbine Generator
Pump
Pump
Condenser Cooling Water

used, or to the air if cooling towers are used.

Obviously, not all the heat energy from the reactor is converted to the mechanical energy of rotating turbines. A substantial amount is transferred to the environment through heat transfer in the condenser. This wasted energy is characteristic of all heat engines.

Generator. The basic principle of the electric generator is electromagnetic induction; that is, when a wire is moved in the vicinity of a magnet, an electric current will flow in the wire.

In a power plant, huge coils of wire, driven by the shafts of revolving turbines, spin between the poles of powerful electromagnets. In doing so, the fourth and final energy conversion takes place: the mechanical energy of the turbines is converted into electricity.

CHECKPOINT B

A nuclear power plant converts nuclear potential energy to electrical energy with several steps in between. Fill in the blanks with the form of energy at each conversion. See page 74 for box chart.

PART III: COMPARING A PRESSURIZED WATER REACTOR TO A BOILING WATER REACTOR

In a boiling water reactor (BWR), the water is brought into the reactor and heated until it becomes steam; the steam is used to drive the turbines. About one-third of the reactors in the U.S. today are BWRs. Roughly two-thirds are pressurized water reactors (PWRs). As the name suggests, water at very high pressure passes through the reactor and comes in contact with the reactor core. At such high pressure the water does not boil. The high pressure hot water is piped through a heat exchanger containing cool water pumped from the condenser. The pressurized hot water gives up heat energy to the cool water in the other loop. The water in the second loop changes into steam which drives the turbine.

The PWR and the BWR operate in essentially the same way. However, in the PWR heat is provided indirectly to the steam engine. This indirect heating gives the PWR an advantage over the BWR. Because the coolant does not come in direct contact with the turbine, the turbine area cannot become contaminated with radioactive materials. Higher pressure also allows for more efficient heat transfer and requires a smaller surface area for the fuel core, thus the ideal efficiency of a PWR is high. The need for an additional set of heat exchangers, however, lowers its efficiency.

CHECKPOINT C

1. Which components are alike in BWRs and PWRs?
2. Which components are different?
3. What is the major difference between a PWR and a BWR?
4. List two advantages of PWRs over BWRs.

Student Handout 10–2
The Thermodynamics of Nuclear Power Plants

The energy conversions that take place in a nuclear power plant are governed by the law of conservation of energy, as are all energy conversions.

This law, the First Law of Thermodynamics, states that the total amount of energy within a closed system is conserved, or constant. (A closed system is one that has no energy flowing in or out.) Put more simply, this law states that energy is neither created nor destroyed.

Any conversion of energy from one form to another is governed by this law. Therefore the four conversions that occur in a nuclear power plant obey this law. To review, these are:

1. The conversion of nuclear potential energy to the kinetic energy of the fission products, which takes place within the fuel rods inside the reactor.
2. The conversion of the kinetic energy of the fission products inside the fuel rods to heat energy.
3. The partial conversion of the heat energy produced in the reactor to the mechanical kinetic energy of the turbine. The remainder of the heat energy is exhausted to the environment as waste heat.
4. The conversion of mechanical kinetic energy to electrical energy in the generator.

In the first two conversions, the fuel rods can be viewed as a closed system: despite the fact that heat continuously flows out of the rods, the energy conversions occur entirely within them.

Because much of the energy is lost to the environment in the third conversion, the surrounding environment must also be considered part of the closed system.

In the fourth conversion, the turbine and generator could comprise the closed system. However, since friction and other causes give rise to a small amount of heat in this step, the closed system could also include the environment to which the heat is eventually lost.

The Second Law of Thermodynamics is also crucial to an understanding of the operation of either a nuclear or a fossil fuel power plant. The First Law of Thermodynamics allows for the conversion of energy from one form to another; the only restriction is that the total energy within the closed system must remain constant. But the Second Law of Thermodynamics limits the conversion of heat energy to mechanical energy much further and consequently influences the entire pattern of energy. The Second Law of Thermodynamics states that *it is not possible to convert all of a given amount of heat energy into mechanical energy in the cyclic fashion typical of an engine.* Put another way, no heat or steam engine can be 100 percent efficient in converting heat energy to mechanical energy.

This law applies to the operation of a simple steam engine cycle or a nuclear reactor. After the heated steam has left the reactor and has given up some of its energy to the turbines, it must be cooled and condensed back to water at a low temperature. As this cool water (the coolant) is recycled back into the reactor, it is once again capable of extracting large amounts of heat, as it is boiled to steam at a temperature of 290°C.

Ideal Operating Efficiencies: A French engineer named Carnot derived a mathematical expression for the ideal efficiency of a steam engine in the early nineteenth century. The ideal efficiency of converting heat energy into mechanical energy is expressed:

$$E = \frac{T_1 - T_2}{T_3} 100\%$$

T_1 is the input temperature of the water and T_2 is the exhaust temperature of the water. The temperatures must be expressed in degrees Kelvin for this formula to yield the correct result.

Actual Operating Efficiencies: The actual operating efficiencies of power plants are considerably lower than the ideal efficiencies. Among the reasons for this are:

- the inefficiency of turbines in converting heat energy to mechanical energy,
- the inefficiency of the generators in converting mechanical energy to electrical energy,
- heat losses from various systems within the plant, and
- the power required to run the plant itself, including anti-pollution devices for coal-and oil-fired plants and cooling towers for nuclear and some coal plants.

Waste Heat Disposal: Because approximately 33 percent of the heat energy released in the nuclear reactor is converted to electrical power, the other 67 percent must be released to the environment as waste heat. This heat is carried off by the water that is discharged after circulating through the condenser. Depending on the potential for environmental impact (thermal pollution) one of three methods is used to dispose of waste heat:

1. Water from a large nearby source is pumped through the condenser and returned at a higher temperature to its origin. This method, called once-through cooling, requires a considerable volume of water, which is not used up, but returned to its source.
2. Water is pumped from a cooling pond built especially for this purpose. The heated water is then discharged into the pond, spreads over the surface, and is cooled largely by evaporation.
3. Cooling towers are employed. These are structures in which water is circulated and brought into contact with the air to which it loses its heat.

CHECKPOINT D

Complete the table by answering questions 1 and 2. Then answer questions 3, 4, and 5.

1. What are the operating temperatures of the three types of power plants in degrees Kelvin? (°K = °C + 273°)
2. What is the ideal operating efficiency of a nuclear and coal-fired plant? Using the equation

   $$E = \frac{T_1 - T_2}{T_1} 100\%$$

   find the operating temperatures (°K) of both power plants. Then calculate the ideal efficiencies.
3. The efficiency formula indicates that bringing the coolant (condensed steam) to the lowest possible temperature in the condenser increases efficiency. What restriction places a lower limit on this temperature?
4. The efficiencies of power plants differ slightly in winter and summer. In which season would you expect to get higher efficiency? Why?
5. Operating efficiency indicates that increasing T_2 also increases efficiency. Engineers who design power plants want them to operate at the highest possible temperatures; yet, there is an upper limit on T_1. What constraints could place an upper limit on T_1?

Power Plant Efficiencies

Type of Plant	Operating Temperatures (°C)		Operating Temperatures (°C)		Ideal Efficiency	Operating Efficiency
	T_1	T_2	T_1	T_2		
Nuclear						
BWR	290	38				34%
PWR	325	38				32%
Coal (new)	538	38				38%

Lesson 11

Energy Quality

So far, we have learned that energy can neither be created nor destroyed (you can't win), but that it can be converted from one form to another. However, in the conversion, energy quality (usefulness) is lost (meaning you can't break even). This lesson defines energy quality and then develops an understanding of why quality (usefulness) is lost in energy transformation. Students develop and use a scale of quality for both energy sources and end needs.

OBJECTIVES

Students should be able to:

- Apply the concept of disorder to real world situations.
- Explain why heat engines (heat-to-mechanical conversions) have low efficiencies.
- Develop criteria for ranking energy sources by quality.
- Use these basic criteria for matching energy sources to end uses by quality.

TARGET AUDIENCE

Students of Chemistry, Physics

TIME ALLOTMENT

Two or three class periods

MATERIALS

Student Handout 11-1, "Choosing Disorder"
Student Handout 11-2, "Hypothetical Heat Engines"
Student Handout 11-3, "Moving Pistons"

TEACHING STRATEGIES

Begin by writing the definition of energy quality on the chalkboard:

Energy quality is the ability of an energy source to do useful work as measured by the efficiency with which it can be transformed to mechanical energy.

Ask: Why is energy quality lost in an energy conversion? Elicit as many responses as you can.

Distribute Student Handout 11-1, "Choosing Disorder." Students should be able to complete it in 5-10 minutes. In a class discussion, help the students establish that the more disorderly arrangement is the more probable; that in nature there is an overall tendency for things to proceed toward disorder; and that objects will do this spontaneously if left to themselves.

Answers to Student Handout 11-1

More disordered are: 1B; 2B; 3B; 4B; 5B; 6A.

Next, distribute Student Handout 11-2, "Hypothetical Heat Engines." Ask students to answer the questions. Discuss why the natural tendency toward disorder requires the heat-to-mechanical conversion to have low efficiency.

Answers to Student Handout 11-2

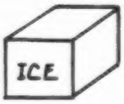
1. Engine #1.
2. To move the load, the load's inertia must be overcome. To keep the load moving, the horizontal moving force must be equal to or greater than the frictional force. The molecules in Engine 1 deliver all their energy to the piston in a short enough time to accomplish the task. The energy of the molecules in Engine 2 is so spread out that the component directed toward moving the load is much smaller than in Engine 1. In other words, there is less entropy (random molecular motion) in Engine 1 and therefore more useful energy available to apply to the task at hand.
3. The conditions represented for Engine 2 are much more probable because molecular motion is naturally random.
4. The heat to mechanical conversion is so inefficient because it involves the conversion of some of the random motion of gas molecules into the orderly straight-line motion of the piston. This goes against the natural tendency of things as described by the Second Law of Thermodynamics. Hence, heat engines turn out to be very inefficient.

Then, have students analyze the three situations described in Handout 11-3, "Moving Pistons." Allow 10-15 minutes for this task. (The natural tendency toward disorder requires that mechanical energy be ranked at the top of the scale of energy quality. This is because mechanical motion is the most orderly—all atoms move the same way. Electrical energy ranks second because electrons are prevented from totally "doing their own thing," since they are constrained to move in a wire. Heat energy is low on the quality scale because molecular motion is disorderly. High temperatures have more quality than low, because the higher the temperature is above ambient temperature, the greater the potential is for doing work.)

1. Highest temperature, Cylinder 1; lowest temperature, Cylinder 3.
2. Most ordered energy, Cylinder 1; least ordered energy, Cylinder 3.
3. Greatest speed, Cylinder 1; stationary, Cylinder 3.
4. Cylinder 1.
5. a. The greater the differences between the energy temperatures in a given system, the higher the quality of the energy in that system.
   b. The greater the entropy, or amount of disorder, in a system, the lower the quality of the energy will be.
6. Cylinder 3.
7. Energy quality tends to decrease over time. Just as energy tends to flow from hot areas to cooler areas, and just as highly ordered energy forms tend to a state of disorder (entropy), so too does high quality energy tend to a state of lesser quality.
8. Ranking from highest to lowest quality:
   1. Mechanical energy
   2. Electrical energy
   3. Heat energy (T=100°C)
   4. Heat energy (T=ambient)

Student Handout 11–1
Choosing Disorder

Shown below are six *pairs* of pictures. Choose the picture in each pair that represents the more disordered state, and write "More disordered" in the blank provided.



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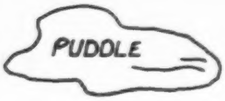

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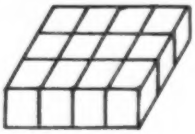

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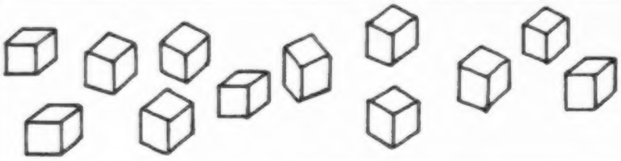

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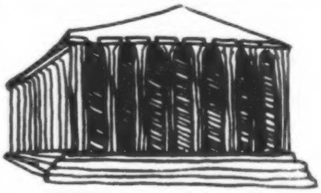

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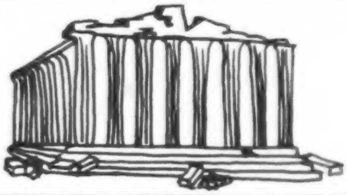

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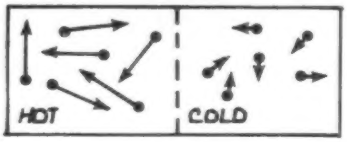

A GAS IN AN INSULATED BOX WITH A POROUS PARTITION

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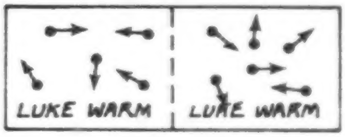
LUKE WARM
LUKE WARM

A GAS IN AN INSULATED BOX WITH A POROUS PARTITION

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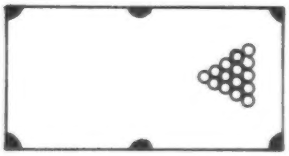

POOL TABLE AND BALLS

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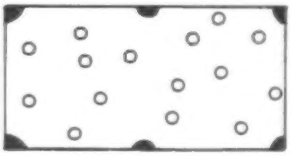

POOL TABLE AND BALLS

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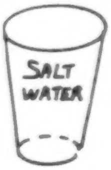

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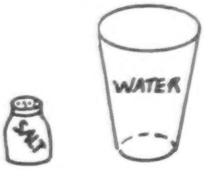

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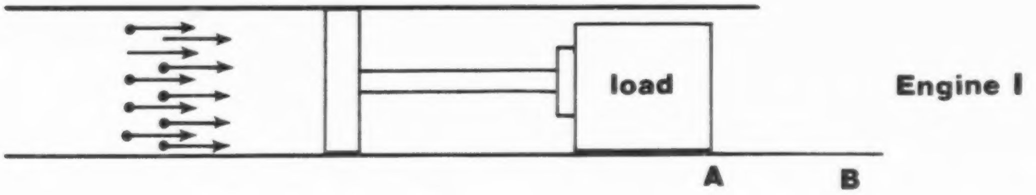
Student Handout 11–2
Hypothetical Heat Engines

Suppose we have two identical heat engines. They both are set up to accomplish a task. The desired task is to have a piston push on a load with sufficient force to move it from A to B.

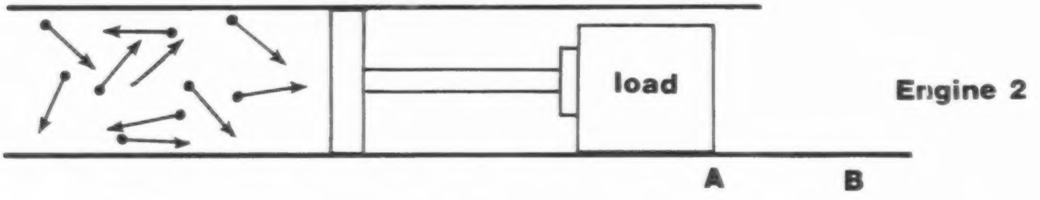
In the cylinder of Engine 1, the molecules possess a certain kinetic energy (E). All the molecules have the same mass, and move in the same direction with the same speed.

In the cylinder of Engine 2, the molecules possess the same total energy (E) as the molecules in the cylinder of Engine 1. They have the same mass and move with the same speed. The only difference is that the molecules in the cylinder of Engine 2 move in random directions.

1. If the load (identical in both cases) moves the full distance in only one of the two cases, which heat engine accomplished the complete task?
2. Why doesn't the load move as far in the other case?
3. Which engine operates under conditions more like the way things are in the "real" world? Why?
4. How does the situation considered in this problem help explain why the heat to mechanical conversion is so inefficient?



Engine I

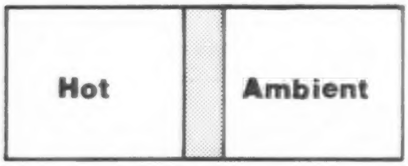


Engine 2

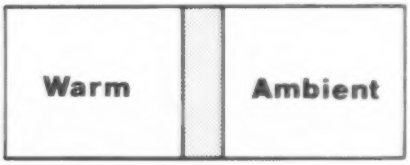
Student Handout 11–3
Moving Pistons

In each cylinder shown below, a piston is located in the center. Air is on both sides of the pistons, and the relative temperature of the air is shown. Ambient means the temperature of the surroundings.

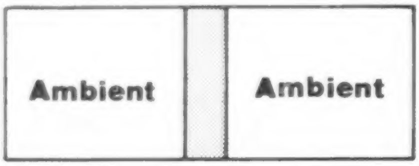
1. Which cylinder has energy at the highest temperature? The lowest?
2. In which cylinder is the energy most ordered? Least?
3. In which cylinder will the piston move with the greatest speed? In which will the piston remain stationary?
4. The terms of the previous three questions are indicators of *energy quality*. Based on your answers, which cylinder contains the highest quality energy?
5. How is the energy quality related to: a. temperature, and b. entropy (disorder)?
6. One of the cylinders above represents the state to which the energy in the other two cylinders will eventually resolve.



Cylinder 1



Cylinder 2



Cylinder 3

Which one is it?

7. Given your answer to question 6, make a statement about the tendency of energy quality.
8. Rank the following in terms of energy quality. Rank items from highest to lowest quality.

ITEMS	RANKING
Heat energy (T=ambient)	1.
Electrical energy	2.
Heat energy (T=100°C)	3.
Mechanical energy	4.

Lesson 12

Ordering Energy by Sources and End Uses

Because some sources of energy are of higher quality than others, and because some end uses require higher quality energy then others, it makes sense to match sources to end use tasks. This lesson helps develop this understanding.

OBJECTIVES

Students should be able to:

- Discuss the ordering of energy by source and end use.
- Explain why matching energy sources to end use tasks makes wise use of energy supplies.
- Apply the matching of source to end use in real world situations.

TARGET AUDIENCE

Students of Chemistry, Physics

TIME ALLOTMENT

One to two class periods

MATERIALS

Student Handout 12-1, "Ordering Energy Sources by Quality"
Student Handout 12-2, "Ordering End Uses of Energy by Quality"
Student Handout 12-3, "Matching Source to End Use"
Transparency Master 1, "New Questions About Energy Use"
Transparency Master 2, "Toward a Sustainable Energy Society"
Overhead projector

TEACHING STRATEGIES

Distribute Student Handout 12-1 and discuss the ranking activity as students complete it. Then place the heading, New Questions About Energy Use, in transparency form on the overhead projector. Discuss the implications of the heading with the class. Then have students complete Student Handout 12-2.

Answers to Student Handout 12-1

1./2. Gravitational potential energy } equal
Mechanical kinetic energy
3. Solar
4. Fossil fuels
5. Biofuels
6. Fusion
7. Fission
8. Geothermal

Answers to Student Handout 12-2

1. Mechanical Motion
2. Electrical devices
3. Heat (T>100°C)
3. Heat (T<100°C)

Next, ask students to apply the general principle of matching end uses with the most appropriate energy sources in some examples of real world situations. Distribute Student Handout 12-3, "Matching Source to End Use." Allow sufficient time for students to complete the exercise. Then discuss each pair with the whole class.

Conclude the lesson by having students discuss the strategies for a national (and personal) entropy ethic.

Answers to Student Handout 12-3

Pair 1. B provides the best quality match. Electricity is high quality energy and using it to heat a home is a mismatch. In B, the high temperature, high quality heat energy from burning coal is used to make electricity and the low quality hot water left over is used for heating. (Note: If the coal-fired power plant is in a city there must be rigorous pollution control.)

Pair 2. A is the best quality match because communication, etc. are high quality end uses which require electricity.

Pair 3. B is the best quality match. In a passive solar home, solar energy is converted directly to heat energy at high efficiency. In a photovoltaic cell, solar energy is *upgraded* at *low* efficiency to electricity, which is high quality energy and should not be used for the low quality end use of space heating.

Transparency Master 1
New Questions About Energy Use

Until recently, the major questions about our energy crisis were:
a. For what purposes will we require energy in the future?
b. How much energy will we require?
Because of these questions, our major concerns have been: (1) increasing exploration for fossil fuels, (2) expanding distribution systems, (3) improving the design of devices that use large supplies of energy, and (4) regulating energy production and use.

The concept of energy quality compels us to ask some new questions and to consider consumption and conservation in a new light. Since sources and end uses differ in quality, we must now ask: What kind of energy should be used to accomplish a particular task? The source consumed should match the task to be performed. Chain saws are appropriate for cutting wood. They are not appropriate for cutting butter.

Transparency Master 2
Toward a Sustainable Energy Society

Energy can be neither created nor destroyed, but merely transformed from one form to another. In these transformations, energy quality, or usefulness, is lost as matter proceeds to its most probable—most disordered—state. Therefore, we do not have an energy crisis; we have an energy quality crisis.

In an energy-dependent society such as ours, it makes sense to carefully manage the use of energy quality. We need to realize that the brake is as important as the throttle. Applying the brakes may mean:

1. Changing our lifestyles (doing things that consume less energy);
2. Redesigning our technology (more energy-efficient cars and buildings are two examples);
3. Discovering new energy sources that are plentiful and environmentally acceptable; and/or
4. Matching the quality of energy sources to the requirements of the end use.

There is no one solution to the energy crisis. The path we follow is not clearly marked or understood. It is obvious, however, that we will need insight into the nature of energy and the laws that regulate its flow.

Discussion Points to use with Transparency Master 2

A logical energy future would use quality energy sparingly, because of its value. We will, therefore, need energy conservation in its broadest sense: not only curtailment, but also improvements in conversion and end use efficiency and changes in the process and structure of our industrial society. Energy should be used only when necessary and then used in a manner that conserves its quality.

Quality conservation, for instance, would allow us to generate electricity from the high temperatures obtained by burning coal or wood and to heat homes or power manufacturing processes with the waste heat from the turbine. (District heating and co-generation are ways of accomplishing these quality-conserving goals.) It would lead us to use high quality electricity to run cars and motors (a high quality end use) rather than to upgrade thermal energy from the burning of gasoline or diesel oil.

Conservation in this broad sense would bring additional benefits to society. Bicycling and walking not only save energy, they also improve health. Conservation reduces pollution, since pollution accompanies almost all of our energy conversions. Attention to efficiency and quality matching also shifts investment from energy production. Since the energy producing industries are the most capital-intensive ones we have—they put dollars rather than people to work—this would both free investment capital for other purposes and create more jobs.

Thus there is much to gain from an understanding and application of the laws of thermodynamics that govern the flow of energy.

Student Handout 12–1
Ordering Energy Sources by Quality

Below is a list of various energy sources and their *operating* temperatures. The temperatures indicate the *relative* quality of each source, although the temperatures are not exactly comparable. Rank the sources from highest to lowest quality.

Sources	Equivalent Temperature (°K)	Sources Ranked by Quality (Listing from Highest to Lowest Quality)
Fission (Reactor Temperature)	800–900	1. ____________
Biofuels	1800	2. ____________
Mechanical Kinetic Energy—Wind and Water	∞	3. ____________
Fusion (Temperature of the Absorbing Medium)	773-1273	4. ____________
Gravitational Potential Energy—Water	∞	5. ____________
Solar (Black Body Temperature)	5800	6. ____________
Geothermal	300	7. ____________
Fossil Fuels (Flame Temperature)	2500	8. ____________

Student Handout 12–2
Ordering End Uses of Energy by Quality

People use energy to accomplish certain tasks. These tasks are called *end uses*. End uses can be classified by their quality just as energy sources are. For example, providing mechanical energy is a high quality end use, and heating a room to 70°F a fairly low quality end use. It makes sense to match the quality of the source with the end use. If a low quality source (heat energy) is used for a high quality end use, in a motor, for instance, it is inefficient. If a high quality source is used for a low quality end use, then we are throwing away energy quality that could be used to do something else. Rather than heat a room with the approximately 2000°C of a coal furnace, you could make steam, generate electricity, and use the exhaust steam to heat the room. In an energy-dependent society such as ours, it is important to perform a task with the lowest quality energy that can accomplish the task. The chart below lists some end-use tasks performed in the United States. Rank these four end uses by the quality of energy required to accomplish the task. Rank them from the highest quality energy required to the lowest.

END USES	RANKING
Heating at temperatures less than 100°C (for instance, heating a home)	1. ________
Heating at temperatures greater than 100°C (for instance, smelting steel)	2. ________
Mechanical motion (for instance, powering an automobile)	3. ________
Electrical devices (for instance, home appliances and lighting; electrometallurgy; electronic communication)	4. ________

Student Handout 12–3
Matching Source to End Use

In this exercise, you are given pairs of sources and end-use strategies. Select the strategy that represents the best source-to-end-use match from an energy quality standpoint. Give your reason for making the selection.

Pair 1.

A. A home is heated electrically (resistance strip heater). The electricity is produced at a distant nuclear generating plant.

B. A home is heated by piped hot water from a nearby electrical coal-fired power plant.

Pair 2.

A. Electricity is restricted to such uses as powering electronic devices, electromechanical processes, and electric motors in home appliances and vehicles.

B. Electrical consumption is expanded to include the heating of homes and the provision of industrial heat.

Pair 3.

A. A home is heated electrically using photovoltaic cells. The electricity produced by these cells runs the motor of a heat pump (a device for moving quantities of heat around—like a refrigerator does) for daytime heating. Extra electricity is used to electrolyze water and produce hydrogen and oxygen. At night, fuel cells produce the electricity for the heat pump by recombining the hydrogen and oxygen.

B. A home is built to act as a passive collector of solar energy in the winter and a rejector of solar energy in the summer. Because of its design, natural convection currents circulate collected heat throughout the home during the winter months. Hand-drawn insulating drapes prevent the escape of heat at night.

Lesson 13

What Determines Appropriateness?

Many factors determine the appropriateness of an energy technology for a specific end use in a specific community. Among these factors are the match between energy quality and end use, the match between size of production and end use systems, and resilience and cost-effectiveness of fuel. Geography, climate, and lifestyle also influence appropriateness. In this lesson, students consider the quantitative impact of these factors on energy choices.

OBJECTIVES

Students should be able to:

- Classify energy sources according to renewability, degree of centralization, quality, and overall appropriateness.
- Define appropriate technology.
- Rank various sources and end uses according to the quality of energy produced and required.
- State some geographical and meteorological factors that affect appropriateness.
- Perform calculations involving laboratory work, degree days, hydropower potential, and solar radiation.

TARGET AUDIENCE

Students of Chemistry, Physics

TIME ALLOTMENT

Three to four class periods

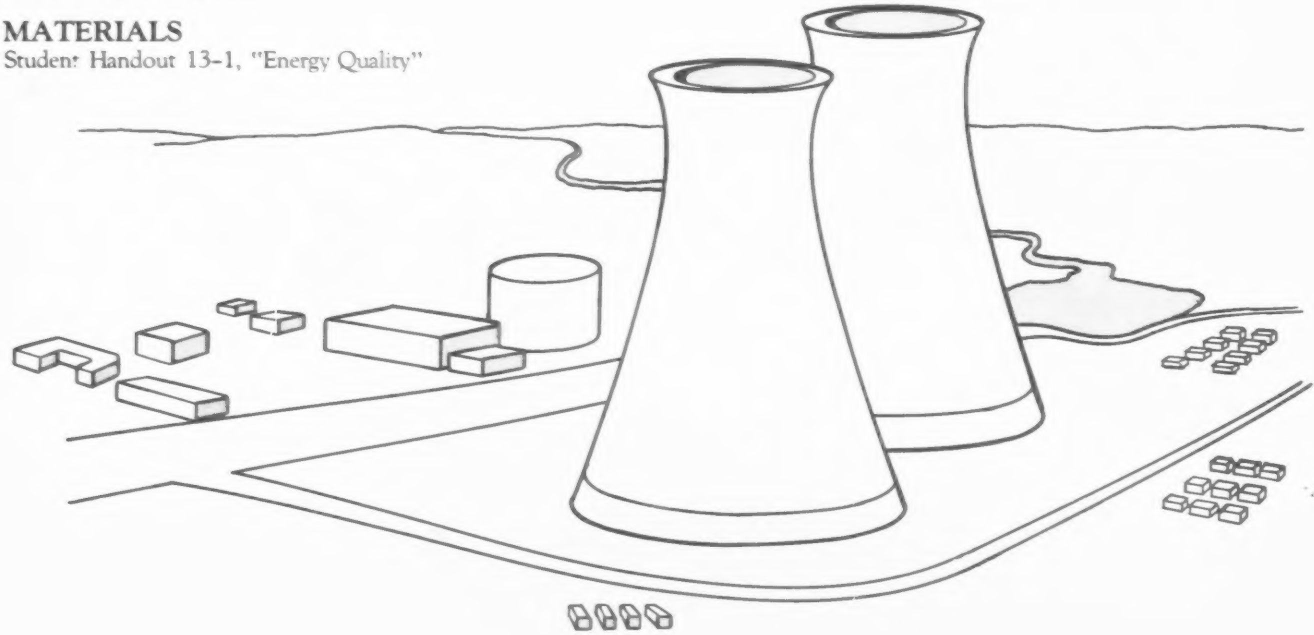
MATERIALS

Student Handout 13-1, "Energy Quality"
Student Handout 13-2, "Classifying Energy Sources and Uses"
Student Handout 13-3, "Weather and Location Affect Appropriateness"
Thermometer
Hot plate
Bunsen burner
Ring stand and ring
Safety goggles
Balance
Wire gauze
Water
Beaker tongs

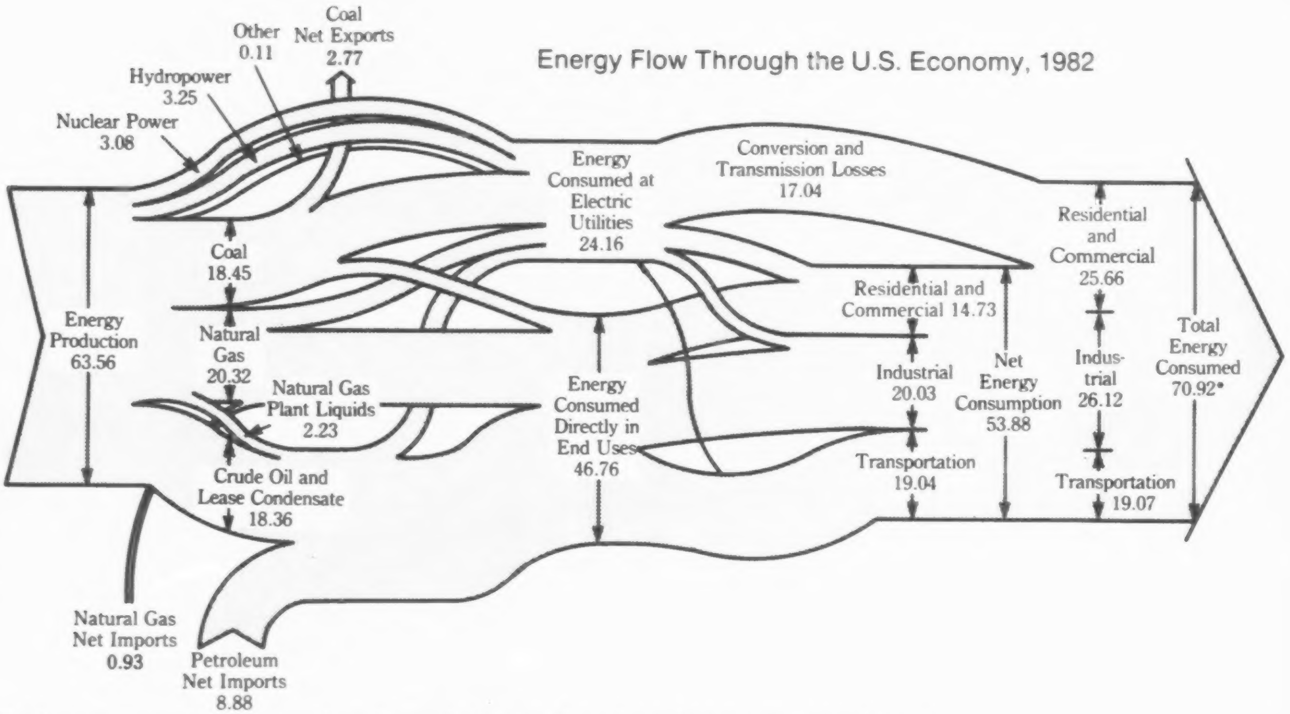
TEACHING STRATEGIES

Energy quality is the ability of an energy source to do useful work as measured by the efficiency with which it can be transformed to mechanical energy. This is a difficult concept to convey to students without examining randomness and entropy. In this lesson, energy quality is linked to the production of waste heat during energy conversions.

Start off with a discussion about waste heat. Begin by defining it and showing the picture of cooling towers at a nuclear power plant below. Explain that waste heat is also produced at fossil fuel plants. Where else might waste heat be found? (Waste heat is produced in any energy conversion. Examples: automobiles, electric lights and appliances, manufacturing and industry, etc.)



A discussion of the problems associated with the disposal of this waste heat would be suitable here.


Energy Flow Through the U.S. Economy, 1982
Coal Net Exports 2.77
Other 0.11
Hydropower 3.25
Nuclear Power 3.08
Energy Production 63.56
Coal 18.45
Natural Gas 20.32
Natural Gas Plant Liquids 2.23
Crude Oil and Lease Condensate 18.36
Natural Gas Net Imports 0.93
Petroleum Net Imports 8.88
Energy Consumed at Electric Utilities 24.16
Conversion and Transmission Losses 17.04
Energy Consumed Directly in End Uses 46.76
Residential and Commercial 14.73
Industrial 20.03
Transportation 19.04
Net Energy Consumption 53.88
Residential and Commercial 25.66
Indus-trial 26.12
Transportation 19.07
Total Energy Consumed 70.92*

*Total energy consumption with conversion and transmission losses allocated to end use sectors in proportion to the sectors' use of electricity. Sum of components do not equal total due to the use of preliminary conversion factors.

Show the students the figure, "Energy Flow Through the U.S. Economy, 1982." Students will probably be surprised at the amount of energy waste. Point out that most of this waste comes from the generation and transmission of electricity; that most of the waste is assigned to the residential sector; and that much of this waste could be eliminated by proper matching of end use quality with source.

Put the energy quality hierarchy given below on the chalkboard.

HIERARCHY OF ENERGY QUALITY

Type of Energy	**Energy Quality**
Mechanical	High
Electrical	
High Temperature Heat (Above 180°C)	
Medium Temperature Heat (100 to 180°C)	
Low Temperature Heat (Below 100°C)	Low

Ask: Are the energy sources we most often use matched in quality to the end uses to which we put them? (Two examples of a mismatch between source and end use are the use of high quality electricity to produce low quality space heating; and the automobile, where high temperature heat is converted to mechanical energy. The waste heat in this second example can be demonstrated by having the students put their hands over the exhaust or muffler of a car.)

Distribute Student Handout 13-1, "Energy Quality." In this lab students will compare the efficiency of an electric hot plate and a laboratory Bunsen burner. In order for the results to confirm the premise of the lesson, several precautions should be taken. First, make sure that each student starts with a cool hot plate that is turned off. The amount of electricity needed to heat the hot plate must be included in the total amount of electricity used. Second, be sure that the Bunsen burner flames are adjusted for maximum use of the fuel.

The lab calculations may be easy or time-consuming, depending on the ability level of your students. You may want to simplify the calculations if you feel that the point will be lost in the process.

Discuss the questions at the end of the lab. Students should demonstrate an understanding of matching quality of source with end use.

Answers to Student Handout 13-1

1-5. Student calculations should be checked individually.
6. Electric hot plate.
7. Probably would have been more difficult to reproduce the experiment with coal—but no, the results would be similar. (Procedures would be much more difficult.)
8. Gas stove.
9. Electricity. Gas can only fuel heat sources such as stoves, furnaces, hot water heaters, dryers. Electricity can supply energy for almost anything in the house.
10. Low. High.
11. Answers will vary, but could include solar energy, a candle, waste heat from cooling of lights.

12. No. It would be very difficult to heat a house to a comfortable temperature with only 21°C air (especially if it was -28°C outside or the house was not well-insulated.)
13. Student answers will vary. Several possible responses are: electricity for space heating; high temperature heat for mechanical energy in running a car (it would be more efficient to upgrade electricity); electricity to pump water (a direct mechanical conversion such as a windmill would be more efficient); electricity to run power tools; electricity for cooking.

Next, discuss these terms and their definitions with students.

Renewable resource: a resource that is capable of providing meaningful amounts of energy for centuries provided we do not overtax the ability of that resource to replenish itself. Example: solar energy.

Nonrenewable resource: a resource that could become exhausted in 50 to 500 years at current rates of consumption and that could not be replenished in the next 1,000 years. Example: fossil fuels.

Centralized energy systems: energy systems that are characterized by very large production facilities and widespread distribution networks. In other words, energy is produced at a central site and distributed for use over a wide geographical area. Example: nuclear power plant.

Decentralized energy systems: energy systems that are characterized by small, "self-contained" production facilities that do not need distribution systems, or need only local distribution. In other words, energy is produced and used at the local site, or at most in a community or a limited geographic area. Example: wood stove burning local wood.

Distribute Student Handout 13-2, "Classifying Energy Sources and Uses," and have students classify the sources and systems according to the definitions given in class. Then, using the hierarchy of energy quality from the lab, have students evaluate the match between the source and use in each item.

Answers to Student Handout 13-2

	Renewable/ Nonrenewable	*Centralized/ Decentralized*	*Matched in Quality?*
1.	N	C	No
2.	N	C or D	No
3.	R	D	Yes
4.	R	D	Yes
5.	R	D	Yes
6.	R	D	Yes
7.	R	C or D	Yes
8.	N	C or D	No
9.	R	D	Yes
10.	N	D	Yes
11.	R	C	No
12.	N	D	No
13.	R	D	No
14.	N	D	Yes

Distribute Student Handout 13-3, "Weather and Location Affect Appropriateness." Ask students how they think weather and location might affect the appropriateness of an energy technology. Using wind, hydro, or geothermal in a place where that source is plentiful is more appropriate than transporting that energy elsewhere or importing energy from another place, because it is efficient in terms of money and energy. The boom in wind and geothermal electricity production in California and the consistently low price of electricity from hydropower in the Northwest are two good examples. In addition to proximity, coincidence of need and availability can make one technology more appropriate than another. For example, solar is often the most appropriate source for air conditioning because of the peak of solar availability during the hottest hours.

Answers to Student Handout 13-3

Part I

Students must do calculations in 3 steps: (1) find the difference between the average temperature given and 65°F; (2) multiply the difference by the number of days in the month; and (3) sum heating degree days and cooling degree days separately.

Chicago, IL	5984 heating degree days per year
	789 cooling degree days per year
Helena, MT	7808 heating degree days per year
	93 cooling degree days per year
Houston, TX	1117 heating degree days per year
	2663 cooling degree days per year
Washington, DC	4348 heating degree days per year
	1073 cooling degree days per year

1. Helena has the most severe winters and is generally the coldest locale. Houston has the hottest summers and is generally warmest. Washington has the widest spread, cold winters and hot summers. Chicago appears to be generally cool.
2. Cooling is probably not necessary in Montana because the number of cooling degree days is so low. Students may also observe that the average daily temperatures above 65°F are very mild; and they may know that the humidity is generally low in Montana. In Houston, however, heating is probably needed. The number of heating degree days is fairly substantial, even though the average daily temperatures below 65°F are also mild.

Part II

1. Radius of the earth = 6.3×10^3 km = 6.3×10^6 m
   Surface area of the earth = $4\pi r^2$
   $= 4(\pi)(6.3 \times 10^6)^2$
   $= 5.0 \times 10^{14}\ m^2$
   Solar radiation/m^2
   $= 5.82 \times 10^{22}$ joules/day/$5.0 \times 10^{14}\ m^2$
   $= 1.2 \times 10^8$ joules/day/m^2
2. a. Latitude.
   b. Cloud conditions.
   c. Time of year.
   d. The amount of atmospheric absorption, which depends on altitude and many atmospheric effects.
   e. The angle between the collecting surface and the sun.

These factors are difficult to predict. It is often easier and more useful to determine the actual amount of solar energy hitting the ground on-site.

Part III

1. $g = 9.8\ m/sec^2$
   One m^3 of water has a mass of 10^3 kg
   Potential energy = mgh
   $= (10^3\ kg)(9.8\ m/sec^2)(1\ m)$
   $= 9.8 \times 10^3$ joules
2. The potential energy of 7 m^3 of water at a height of 15 m = mgh. (7 m^3 has mass of 7000 kg)
   $= (7 \times 10^3\ kg)(9.8\ m/sec^2)$ 15 m
   $= 1.03 \times 10^6$ joules

Since 7 m^3 of water falls every second, the energy available per second or the power potential of this stream is:

$$1.03 \times 10^6 \text{ watts or}$$

$$1.03 \times 10^3 \text{ kilowatts.}$$

A general formula may be presented to the students. If Q is the flow rate in cubic meters/second, and H is the head in meters, the power (in kilowatts) available is then given by the formula:

$$\text{Power} = 9.8 \times H \times Q.$$

3. The efficiency accounts for friction in pipes and inefficiencies in turbine, generator, and any mechanical connections.

The power delivered by the system:

$$= .5(1.03 \times 10^3 \text{ kilowatts})$$

$$= 5.15 \times 10^2 \text{ kilowatts}$$

$$\text{Power} = 9.8 \times H \times Q \times E$$

where E is the efficiency of the system

4. $$\text{Power} = (9.8)(H)(Q)(E)$$

$$50\% \text{ of power} = 2500 \text{ kw}$$

$$2500 \text{ kw} = (9.8)(H)(.5)(.40)$$

$$\frac{2500}{(9.8)(.5)(.40)} = H = 1275 \text{ m}$$

No, this is totally ridiculous. It would require the town to build a dam that is 1275 m high.

Student Handout 13–1
Quality of Energy

We use a variety of energy sources to produce heat. Buildings can be heated with coal, wood, oil, natural gas, solar power, or electricity. Each of the sources has advantages and disadvantages depending on factors such as location, structure, and specific heating requirements. In this lab you will compare electric heat (from a hot plate) with gas heat (from a Bunsen burner). Because most electricity is produced by converting heat energy to electricity, the two sources will be compared by the amount of fuel consumed to produce the heat needed in this experiment. Therefore, the heat from natural gas will be measured directly; the heat from electricity will be measured indirectly by calculating the original heat needed to make the electricity to make the heat for this experiment.

PROCEDURE

1. Record the mass of the empty beaker.
2. Add exactly 200 ml of room temperature water to the beaker.
3. Find the power rating on the hot plate and record it. (It will be measured in watts.)
4. Record the exact temperature of the water in the beaker.
5. Place the beaker on the hot plate. Note the starting time.
6. Turn the hot plate to the highest setting.
7. Continue to heat the water until the temperature has been raised by 40°C. Record the amount of time.
8. Turn off the hot plate.
9. Position the Bunsen burner under the ring stand so that a beaker placed on the ring can be heated by the flame.
10. Cool the beaker. Then add exactly 200 ml of room temperature water and record the temperature.
11. Place the beaker on the ring stand, light the burner, and again find the length of time necessary to raise the temperature of the water by 40°C. Record the amount of time.
12. Clean up your materials.

DATA

Mass of empty beaker __________g

	Hot Plate Trial	Bunsen Burner Trial
Temperature of Water:		
Start	________°C	________°C
Finish	________°C	________°C
Time for Heating	________ Min	________ Min
Power Setting	________ Watts	

CALCULATIONS

1. Find the number of kWh of electricity that the hot plate used.
   kWh = (watts divided by 1000) × (min divided by 60)
   = ________kWh
2. If the electricity were produced in a plant that used natural gas for fuel, an average of 10.2 cubic feet of gas would be burned to produce 1 kWh of electricity. Calculate the total number of cubic feet of gas you used. In addition, there are transmission losses of approximately two-thirds.
   Cubic Feet = (________kWh) × $(10.2\ \frac{ft^3}{kWh})$
   = ________ft^3 + (answer × .66) = ________ft^3.
3. Approximate the amount of gas used by the Bunsen burner through the following calculations.
   Total amount of heat needed = (mass beaker × specific heat glass) + (mass water × specific heat water) × temperature change
   Total heat = (______g × $.20\ \frac{cal}{g\ °C}$) + (200 g)$(\frac{1\ cal}{g\ °C})$
   × 40°C = ______cal divided by 1000 = ______kcal
4. Because much of the heat produced by the burning gas is wasted, estimate the total amount of heat as *twice* your calculation in question 3.
   Total Heat (including losses) = ______kcal
5. Find the number of cubic feet of gas used. On the average, natural gas produces 260 kcal/ft^3.
   Cubic Feet = (______kcal) ÷ (260 kcal/ft^3)
   = ______ft^3
6. Which method uses more natural gas?
7. If this experiment had been done using other fossil fuels (coal, oil) instead of natural gas, would the results be different?
8. Based on the results of this lab, which is a more appropriate technology—a gas stove or an electric stove?
9. Both natural gas and electricity can be delivered to your home. Which source is more versatile? Explain.

HIERARCHY OF ENERGY QUALITY

Type of Energy	Energy Quality
Mechanical	High
Electrical	
High Temperature Heat (Above 180°C)	
Medium Temperature Heat (100 to 180°C)	
Low Temperature Heat (Below 100°C)	Low

10. According to the chart, what quality energy was *needed* in this lab to heat the water? What quality energy was *used*?
11. Natural gas burns at temperatures greater than 180°C. Try to think of some *source* of energy that would be exactly matched in quality to the *end use* of this experiment.
12. Do you think that a heat source providing hot air at a constant temperature of 70°F and a home needing space heat would be well matched in quality? Why or why not?
13. Give *three* examples of other energy end uses which are mismatched in energy quality to their customary energy sources.
    a.
    b.
    c.

Student Handout 13–2
Classifying Energy Sources and Uses

Sources and Uses	*Renewable/ Nonrenewable?*	*Centralized/ Decentralized?*	*Matched in Quality?*
1. Private home heated by a natural gas burner in the basement			
2. Thirty-story apartment building in Chicago heated by an oil furnace in the basement			
3. Water in a high school swimming pool heated by a solar hot water system on the roof			
4. Water for irrigation pumped by a windmill on a Kansas farm			
5. A Vermont home heated by a wood stove			
6. Mechanical power for a sawmill supplied by a waterwheel on an adjacent system			
7. Electric cable cars in San Francisco (electricity produced from geothermal steam)			
8. Greyhound bus			
9. Solar greenhouse			
10. Nuclear submarine			
11. Electric stove (electricity produced at the Glen Canyon Dam)			
12. Propane camp stove			
13. Tractor fueled by alcohol produced by fermenting corn from the farm			
14. Flashlight			

Student Handout 13–3
Weather and Location Affect Appropriateness

Geography and climate are two closely related elements that affect energy sources and uses. Obviously, the proximity of energy sources to a location of use—a coincidence of geography—can influence the appropriateness of the sources. Energy sources like wind and solar are only appropriate where they are available. As technology has expanded, so have the areas of availability. The more transportable sources tend to become more expensive as they are shipped farther from their origins. The high price of oil in New England is one good example; the low price of hydroelectricity in the Northwest is another.

Other obvious criteria for appropriateness of direct solar applications are the ratio of sunny to cloudy days at a certain location, and the intensity of the solar radiation that is available. The latter depends on latitude, the former on weather patterns.

But far and away the most influential factor is temperature. Temperature determines how much energy is needed to heat or cool a space. Furnaces have always been sized not only according to the amount of space to be heated, but the degree of cold to be relieved. Less energy-rich cultures have conserved energy by using building materials that cut the extremes of temperature and thus decrease heating and cooling needs. Building with adobe in the Southwest and ice in the Arctic are two examples.

Heating and cooling needs are measured in degree days. A degree day relates energy consumption to outdoor air temperature. Heating degree days are the difference between 65°F and the average daily temperature when the temperature is below 65°. Cooling degree days are the difference between ambient (65°F) and average when the average daily temperature is above 65°F. So, a day when the average temperature was 40°F would be recorded as 25 heating degree days; an average daily temperature of 78°F would equal 13 cooling degree days.

PART ONE
The average daily temperature for four cities is given below.

Find the annual number of heating degree days and cooling degree days for each city. (Remember to find the degree days per month before totalling degree days for the year.) Or find the average daily temperature for your town or area in a world almanac and calculate the annual number of heating and cooling degree days.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chicago, IL	24	27	37	50	60	71	75	74	66	55	40	29
Helena, MT	20	24	33	44	52	60	67	66	56	45	33	25
Houston, TX	53	56	63	69	75	81	83	84	79	71	62	54
Washington, DC	35	36	44	54	65	73	78	75	69	58	47	37

1. Based on your answers, how would you rate the severity of the heating and cooling seasons in these cities?
2. How necessary is cooling in Helena and heating in Houston?

PART TWO

1. The amount of solar radiation intercepted by the earth is 5.8×10^{22} joules/day. The radius of the earth is 6.3×10^3 km (6.3×10^6 m). Surface area of the earth is $4\pi r^2$. Calculate the amount of solar radiation that falls on 1 m^2 of the earth's surface.
2. List five factors that affect the actual amount of solar radiation hitting a surface in a particular area on a particular day.
   a.
   b.
   c.
   d.
   e.

PART THREE

Two factors determine how much power a particular hydroelectric site may produce: (1) the flow, the amount of water passing by, measured in cubic meters per second; and (2) the head, the height the water falls between intake and turbine, measured in meters. The power potential of the site can then be matched to the amount of power needed.

1. Calculate the potential energy of a cubic meter of water at a height of one meter. Potential energy = (mass)(gravity)(height).
2. Calculate the power potential of a stream with a flow of 7 m^3/sec and a head of 15 m. Use the formula $P = 9.8 \times H \times Q$, where P = Power (in kilowatts), H = Height (in meters), and Q = Flow (in meters^3/sec).
3. A hydropower system is installed in the stream in question #2. If it has an efficiency of 0.5, how much power will the system deliver?
4. A small community (population of 3000) requires 5000 kWh of electricity. A stream runs through the town with a flow of 0.5 m^3/sec. What head would be required to supply 50 percent of this town's electricity? (Use an efficiency of 0.4). Do you think this would be an appropriate alternative technology for this town? Why?

Lesson 14

How To Get Better Mileage From Your Car

Mpg, miles per gallon, is part of the vocabulary that heralded the new energy awareness. Low mpg is caused by mechanical factors to some degree; but the greatest determinant is personal driving habits. After students study how mpg is calculated by the Environmental Protection Agency, they measure the mpg of a personal car and examine ways to improve its energy efficiency.

OBJECTIVES

Students should be able to:

- Define mpg and explain how it is calculated.
- Describe strategies to improve automobile mpg.
- List the poor driving habits that lower mpg and ways to correct them.

TARGET AUDIENCE

Students of General Science, Driver Education

TIME ALLOTMENT

Three to four class periods

MATERIALS

Student Handout 14–1, "Calculating Mpg"
Student Handouts 14–2A–D, "Driving Smarter"
Student Handout 14–3, "How To Become an Inefficient Driver"

Activity 1

Distribute Student Handout 14–1, "Calculating Mpg," several days in advance of this activity to allow students time to obtain the readings necessary for the in-class calculation of their mpg. If most of your students or their families do not have cars, performing this as a group activity may be more feasible. Divide the class into small groups, with one car-owning or -using student per group. Have this student perform the activity as stated in the handout and then bring his or her readings to class. Each group will then calculate the mpg for their "group car."

Another option would be for you to perform the activity using your car, and have the class as a whole (or each student individually) calculate the mpg. (Students will need their calculations later in this lesson.)

Activity 2

Distribute Student Handouts 14–2A–D, "Driving Smarter." Students should read the four articles and complete the checkup questions. (This can be done in class or as a homework assignment.) To initiate a follow-up discussion of this topic in class, pose this question: The key to efficient driving is to adjust one nut: Which one? (The "nut" behind the wheel.)

Answers to Student Handout 14–2

Article A
1. b
2. b
3. d
4. c
5. b
6. Answers will vary.

Article B
1. T
2. T
3. F
4. F
5. T
6. F
7. F
8. F

Article C

I. Getting To and From Work
   1. Carpool.
   2. Ride the bus.
   3. Walk.
   4. Bike.

II. Household Driving
   1. Set up a ride-sharing routine.
   2. Call ahead to stores—shop around by phone, not by car.
   3. Set limits on the number of trips you make.
   4. Combine several errands into one trip.

III. Recreation
   1. Reduce your use of gas-consuming recreational vehicles (such as motorboats).
   2. Substitute a short recreational trip for a longer one.

Article D
1. Advantages: improves gas mileage by about 5 percent; Disadvantages: costs more than regular oil.
2. Advantages: saves gas; Disadvantages: can be expensive.
3. Advantages: helps improve mpg; Disadvantages: some drivers got worse mileage using vacuum gauges.
4. Advantages: shows speed that will yield the best mpg; can also help drivers figure out the best routes, times of day to travel, and costs of short trips; Disadvantages: expensive; usually involves a short delay in the meter's calculations; meter may be of little use in rapidly changing conditions; often shows you what you already know.
5. Advantages: prevents unintentional speeding and variations in speed, instead of constant accelerator pressure (i.e., reduces gas economy when driving uphill); Disadvantages: can't be used in city driving.

Activity 3

Distribute Student Handout 14–3, "How to Become an Inefficient Driver." This handout lists 15 tongue-in-cheek "rules" designed to provoke further thought. After students complete this activity, discuss the answers with the class. To extend this activity, you could have students make up their own inefficient rules; another option would be to have students correct several of the listed rules so that they would state "how to become an *efficient* driver."

Answers to Student Handout 14-3

1. Running your engine a shorter time doesn't necessarily mean that you're using it more efficiently. By taking off from a stop as fast as you can—making a "jack-rabbit start"—you lose unburned fuel—half to twice as much as you burn. However, accelerating *too* slowly also wastes gas. Accelerating from a stop briskly but smoothly is the most fuel-efficient technique.
2. This is true if your engine doesn't "knock" with the cheapest gasoline; but if your engine does knock you are not benefitting completely from the fuel you are now burning. Knocking results from uneven combustion, which means that the energy that is released in combustion is not channeled effectively in operating the engine. Think about the carnival game in which you aim a water pistol at a target to cause an object to rise. The most effective strategy is to aim the water directly perpendicular to the target. Anything slightly off results in decreased performance. The same is true with engine knock—and could damage your engine. On the other hand, there is no point in buying more expensive fuel than you need to eliminate engine knock.
3. The reason oil gets dirty is that it absorbs waste products from fuel combustion in your engine. If you don't change your oil and oil filter regularly, these waste products continue to accumulate and possibly damage your engine, as well as affect its performance.
4. Studies have shown that at least half of the tires on the road today are underinflated. You cannot tell by appearance alone whether your tires are inflated to the correct pressure. Every 2 psi underinflation can mean a one percent mileage loss. Keeping your tires inflated to their marked maximum (by regularly checking them with a tire gauge) can help you increase your mpg. Now that most service stations are charging for road maps, the only free services they still offer are rest rooms and compressed air. Free compressed air is a bargain you shouldn't pass up!

   Wheel alignment, which has to do with your tires, also affects your fuel economy. If your wheels are not aligned, part of the energy from your engine will move your car sideways rather than forward.
5. True, you don't want to run your battery down, and your car's air conditioning would do that in almost no time. But the purpose of the gasoline in your car is to move it, not run accessories like air conditioning or the radio. Even when you're driving, you should use your accessories wisely, because they decrease your gas mileage—up to 13 percent for air conditioning. (However, in highway driving, keeping the windows closed and turning on the air conditioner may actually use less gas than driving with the windows open, which increases air resistance.) But if your car is stopped for more than 30 seconds, turn the engine—and your accessories—off.
6. This is one kind of gathering to avoid! Rush hour means more starts and stops and just plain standing still. At such low speeds your car is very inefficient, especially with all the braking and idling thrown in.
7. Every 100 pounds of cargo in your car reduces gas mileage one to two percent. Just as you need to plan where you're going in advance, you also need to plan what you take with you.
8. Short trips may use less gas, but they also use gas least efficiently. When the air temperature is 21° F, a 13.5 mpg car gets only about 3 mpg the first mile, and still only about 9.5 mpg in the fourth mile. This is because the energy from the gasoline is going to heat the engine, the oil is not yet lubricating well, and the wheels are not yet warm (at higher temperatures the air pressure in the tires increases, further reducing rolling resistance). So making several short trips, up to five miles each trip, is highly inefficient. If you have several errands, combine them in a single trip and drive to the farthest place first (if it doesn't disproportionately increase the length of your round trip) in order to warm up your engine for greater efficiency. Or, if you can, use the telephone or mass transit: the telephone uses very little energy, and the engines in public buses stay warm all day.
9. If you are stopped for more than 30 seconds, idling your engine uses more gasoline than restarting the engine would. Idling consumes one cup of gasoline in six minutes—that means a gallon in an hour and a half. If you want to be "Johnny-on-the-spot," use your eyes. By looking ahead you can determine several seconds in advance when the car in front of you will move again.
10. There are cases in which this may be true, but remember that such short cuts usually involve extra turns, which also means more starts and stops. Start and stop driving gives the lowest gas mileage, and turning generates extra friction, which not only wears out tires but also consumes more gasoline. The most efficient driving is on a straight level road at a steady speed, so a good energy-saving short cut would be one that eliminates start and stop driving. If you are concerned about idling at a traffic light for more than 30 seconds, turn off your engine while you're waiting.
11. Maybe it will turn green; but if it doesn't you'll have to slam on your brakes. Braking wastes the momentum gained from gas that you've already burned; and accelerating after braking uses a lot of gas to overcome inertia. Instead, anticipate traffic flow and traffic lights about a block ahead in town, and a quarter mile on the highway. If you see a red light ahead, take your foot off the gas pedal and decelerate well in advance of the light until you come within stopping distance. Then, if the light is still red, gently apply your brakes. If the light has turned green, put your foot back on the gas pedal and accelerate smoothly.
12. There may be less friction, but remember that you need *some* friction to drive a car. If the road is slippery, you don't have enough. You will spin your wheels and get nowhere. This represents not only wasted energy but unnecessary wear and tear on your car as well; it is also extremely dangerous.
13. Unless temperatures are extremely cold or you are advised to warm your engine by the manufacturer of your car, this is a waste of gasoline. Instead, warm your engine by driving slowly the first few miles of your trip.

    You should know where you're going before you even step into your automobile. You should plan your trip to include the following: sharing rides with others (this increases your passenger miles per gallon); combining several errands into one trip; avoiding traffic congestion and the start and stop driving it entails. You should ask yourself, "Is this trip really necessary? Could the trip be made by mass transit or replaced by a phone call?"

14. With modern refrigeration, this strategy is ridiculous, and the money saved by buying your milk and bread with your other groceries (once a week should often be enough) will help cover the cost of running your refrigerator. The same considerations apply to going out of your way to take advantage of specials or coupons at several stores. The cost of driving your car a mile is 15¢. It's not worth driving an extra mile to use a 10¢ coupon.
15. In today's world the telephone (and other forms of telecommunication) is an energy bargain. If you don't phone ahead, *you* may be surprised—and angry at having wasted gasoline.

Extending the Learning

Students should now be well equipped to improve the mileage they get from their next tank of gasoline. They should keep a record of the gasoline conserving measures they take, calculate the gasoline mileage as they did at the start of the lesson, and compare the two.

Students can calculate the amount of gasoline a car owner can save per year, as follows: Divide the number of miles driven per year (10,000 to 12,000 average miles/year) by the mpg first calculated. This gives the number of gallons that would have been used *without* gasoline conservation measures. Then divide the number of miles driven per year by the mileage calculated after gasoline conservation measures were taken. This gives the number of gallons that would be used *with* gasoline conservation measures. The difference is the number of gallons saved. Convert this figure to money by multiplying the number of gallons saved by the price per gallon. (In order for this comparison to be accurate the balance between city and highway driving must remain the same before and after gasoline conservation measures are undertaken.)

Student Handout 14–1
Calculating Mpg

All new cars are tested by the Environmental Protection Agency (EPA) to determine their energy efficiency—or fuel economy. The EPA measures fuel economy in a laboratory on a dynamometer, a machine that simulates different driving conditions. (Another way mpg can be measured is to actually drive a motor vehicle on a proving-ground test track.)

The EPA runs two dynamometer tests on each car: one to simulate city driving conditions, and another to simulate highway driving. The estimated mpg figures that these tests provide must be displayed on the window stickers of all new cars.

The EPA fuel economy figures represent only an average mpg estimate. Each driver does not necessarily get the mileage estimated by the EPA. Mpg on the road depends on factors such as speed, weather, road conditions, the car's accessories, and most importantly, on personal driving habits.

You can measure mpg yourself. Fill up your car, your family's car or a friend's car with gas and note the odometer reading. Keep track of your trips—where you went and how many miles you travelled. Refill the tank when it is at least half empty. Note the number of gallons needed and the odometer reading. Then calculate your mpg (total miles driven ÷ number of gallons used).

Student Handout 14–2A
Driving Smarter: To Go Farther For Less

Perhaps you are one of the estimated eight million Americans who have seen the TV film, "Running on Empty." This half-hour movie showed a new kind of road rally, sponsored by the Sports Car Club of America and the Department of Energy.

In these rallies, drivers competed with one another to improve gas mileage. Eight percent of the drivers managed to get better mileage than the EPA rating for their cars.

They did it by driving smarter. And what they did, you can do, too.

First, and most important, drive at or below the 55 miles-per-hour (mph) speed limit. Most cars get the best gas mileage between 35 and 45 miles per hour. Miles per gallon decrease drastically below 30 and above 50. Driving at 55 uses 20 percent less gas, in the average car, than driving at 70.

Don't Idle Around

But maybe you already observe the speed limits, or most of your driving is in town. You can still drive smarter, and save.

First, avoid idling. Tests conducted for the Department of Energy showed that, on the average, one minute of idling uses as much gas as one minute of driving at 30 miles per hour. In other words, you use enough gas to drive half a mile during every minute that you idle.

Also, a minute of idling uses twice as much gas as restarting the engine. So, as a rule of thumb, if you're likely to be in line for more than half a minute, turn off the ignition.

The half-minute rule applies to warm-up time, too. True, your car gets fewer mpgs when the engine is cold, but it gets *zero* mpgs when idling. After the 30-second start-up idle, drive under 35 miles per hour for the first couple of minutes and your car will warm up more efficiently than when idling.

Don't Spill the Milk

One of the gas-saving surprises for careful drivers is the "move on out" rule. Contrary to popular belief, slow acceleration actually wastes gas. "Brisk but smooth" is the best acceleration technique. The quicker your car shifts out of low gear, the more gas you save. But don't employ jack-rabbit starts. They waste the most!

Your car uses the least gas when it is moving at a steady speed. Imagine that you have a bowl of milk sitting on the dashboard, and try not to spill it. That means a steady foot on the accelerator and slowing down without using the brakes. Braking wastes the momentum gained from gas that you've already burned; and accelerating after braking uses more gas than a steady speed would have used. So:

- anticipate traffic flow and traffic lights 10 to 12 seconds ahead (about a block in town and a quarter mile on the highway).
- keep two or three seconds of space between you and the car ahead of you.
- by decelerating well in advance, try to avoid coming to a traffic light when it is red. Starting from a dead stop uses a lot more gas.

Get the Lead Out

An overweight car, like an overweight jogger, burns up fuel at a rapid rate. There's not much you can do to reduce the weight of your present vehicle, but you can avoid carrying around any extra baggage. For example, if you leave those two 25-kilo bags of fertilizer in the trunk for a week before applying them to the lawn, you cheat yourself out of four-tenths of an extra mile you could have traveled on each gallon of gas.

Another surprise awaits those with air conditioned cars. Most of the fuel penalty for air conditioning comes from just carrying that extra weight around, and from running the unit in city traffic. However, some tests have indicated that keeping the windows closed and turning on the air conditioning actually uses less gas, at highway speeds, than driving with the windows open. Open windows increase air resistance.

In the next article, we'll tell you a high-pressure way to increase your mpg three to six percent at no cost, with no inconvenience, and with practically no effort.

1. At what speeds do most cars get the best mileage?
   a) Below 30 mph
   b) Between 35–45 mph
   c) Between 55–60 mph
   d) At 70 mph

2. Suppose you were in a long line of cars at a drive-in bank. Which of the following actions would save the most gas?
   a) Continue to idle the engine while in line
   b) Turn the engine off and on
   c) Use a jack-rabbit start when the line starts moving
   d) All of the above
3. Which of the following causes fuel to burn at a faster rate?
   a) Extra weight
   b) Air resistance
   c) Keeping the car in low gear
   d) All of the above
4. Which is the best technique to use in accelerating?
   a) Move on out slowly
   b) Use jack-rabbit starts
   c) Move on out briskly but smoothly
   d) Always start from a dead stop
5. The article states that you can save gas and money by driving at or below the speed limit. What is the national speed limit?
   a) 45 mph
   b) 55 mph
   c) 60 mph
   d) 70 mph
6. What other resources do you think can be saved by slowing down?

Student Handout 14–2B

Driving Smarter: A High-Pressure Way To Get There Cheaper

Remember way back, years ago, when the neighborhood service station fillled your tires while filling your gas tank with 30-cents-a-gallon gas?

In those good old days, passenger car tires were mostly one size, and many service station attendants recommended inflating them to their 32-pound maximum. The tires would last longer, they'd say.

Later, owners' manuals became the authoritative guides, and tire pressures dropped to 24 or 26 pounds to yield a softer ride.

Well, with gas at $1.20 or so, it's time to go back to 32 pounds, or whatever is the maximum pressure *marked on the tire itself*. This may be eight more pounds of pressure than the manual or the sticker on the door of your car recommends.

The more pressure you put in your tires, up to the stated maximum, the less gas it takes to drive a mile. That's because harder tires have less resistance to rolling.

However, it is useful to maintain whatever difference in pressure between front and back tires the owner's manual recommends. For example, the manual might recommend 24 in front and 26 in the rear, while the maximum marked on the tire is 32. In this case, you should inflate the front tires to 30 and the rear tires to 32.

Saving Seven Cents a Gallon

All tires slowly lose air pressure. One tire company checked 1900 cars and found that 28 percent had tires that were severely underinflated. And tests conducted by tire companies and by others confirm that more pressure means better gas mileage.

In a report to the Department of Transportation, an independent company concluded, after examining test results, that each two pounds of additional pressure in bias-ply (non-radial) tires improves gas mileage by one-and-one-half percent. Because there may be a difference of eight pounds between the owner's manual and the tire manufacturer's maximum, this presents the possibility of a four to six percent gas saving. That's like reducing the price of your gasoline by seven cents a gallon.

These savings possibilities are for highway driving. In town, the percentage will be less, because of the time your car spends idling at traffic lights or being braked to a stop.

The saving from increased pressure will also be less with radial tires. With radials, eight pounds of increased pressure yields about a two-and-one-half percent fuel saving.

Radials, however, give better gas mileage than non-radials when inflated to the same pressure. At full inflation, you should get about three-and-one-half percent better in combined city and highway driving.

To realize these savings, you have to keep your tires fully inflated all the time. This means checking them about once a week when the tires are cold (when the car has been sitting for three hours, or before driving more than one mile).

You'll need your own tire gauge. One can be bought for a couple of dollars.

One last word: Full inflation undeniably produces a harder ride over bumps. But it does not damage the suspension system (as some people believe), and it does not shorten tire life. In some cases it will increase tire life.

In the next article, we'll tell you about gauges and other modifications to your car that may increase mileage.

QUESTIONS

Write T if the statement is true. Write F if the statement is false.

1. Inflated to the same pressure, radial tires give better gas mileage than non-radials.
2. Rolling resistance is greater in under-inflated tires.
3. Harder tires use more gas.
4. Harder tires shorten the life of the tires.
5. Pressure is measured in pounds per square inch.
6. The best place to check for the pressure to put in your tires for increased mileage is in the owners manual.
7. Only non-radial tires lose air pressure.
8. Keeping tires fully inflated means checking them once a year.

Student Handout 14–2C
Driving Smarter: Is This Trip Really Necessary?

By far the best way to save gas is to stay out of your car. But without becoming a recluse, you can cut down on your driving enough to save a bundle of money if you go about it systematically.

First, keep a driving record. It can be a detailed record that would pass an audit by a CPA, or just a small notebook with mileage and gallons entered each time you buy gas. You'll get more benefit if you record the purpose of the longer trips and for a few weeks jot down every trip you make.

With the record, you'll be able to tell how much of your driving is essential. Then you can set a realistic target for reduction.

For many people, a 20 percent mileage reduction for the first three months makes sense. Until you have a month-by-month record for a full year, you won't be able to make steady reductions because your pattern of driving varies too much with the seasons.

It helps to divide your trips into categories such as:

- Work,
- Home (shopping, school, errands), and
- Recreation.

Work

Only you can tell whether it is essential that you drive alone to work every day. But before you decide it is impossible to carpool, and unreasonable to take the bus, bike, or walk, ask yourself: "If gasoline were $10 a gallon, would I still drive?"

Even one day a week of carpooling or riding the bus could cut your work driving by nearly 20 percent.

Home

Household driving is easy to reduce, but only if you keep records. Without records, it is like trying to lose weight without ever stepping on the scales: you could spend a lot of time fooling yourself.

If you chauffeur the kids to school or to little league, work out a ride-sharing routine with a neighbor. Or, if it's safe, insist the kids ride their bikes three days a week, or that they walk every Friday.

If you run numerous errands for yourself or the children, set some limits. Like: only one trip a day, or three days a week, or only between 4:00 and 5:00 p.m.

When shopping for unusual items, call ahead to find a store that has them. Then jot down the miles you saved by not making a useless trip and congratulate yourself.

You also can save gas by combining errands into one trip. A car that has been warmed up gets better mileage than one that is cold. Even if you have to make six stops on a trip, you get better mileage with the warmed-up car, and you'll probably save miles as well.

Recreation

Don't eliminate recreation. But do set a goal of reducing the amount of gas you burn. If you own a motorboat, reduce your use of it (and the drive to the lake) by one fourth. And reward yourself with a dinner out in a nearby restaurant or a visit with friends.

Study your pattern of recreational driving. Then set a modest goal. Each time you subsitute a short recreational trip for a longer one, give yourself a miles-saved credit. And add up the credits once a month.

Goals and Rewards

Goals and rewards are very important, especially if there are several drivers in the household. You may want to keep a chart in the kitchen to record your progress. And, if there are teenage drivers, you may need to make the rewards fairly substantial.

Rewards should be frequent: once a month for children, perhaps once a quarter for adults.

QUESTIONS

Make an outline entitled "Ways to Save Gas." In the first section, list ways to save gas getting to and from work. In the second section list ways of saving gas in household driving and in the third section ways of saving in driving for recreation.

Student Handout 14–2D
Driving Smarter: Gadgets, Slicker Oil, and Other Additives

There's never been a shortage of devices to add onto your car, or to put into your gas tank or crankcase, that claim to give you better gas mileage.

Surprise! Some of them actually work, under some conditions. A few even pay for themselves in gasoline savings.

Among the most worthwhile "additives" are the new improved-friction motor oils. On the average, they improve gas mileage about five percent. And that is equal to saving about six cents a gallon on gas, or 80 cents to $1.00 at each fill-up.

There are two types of improved-friction oils now available at most service stations: regular motor oils with special additives, and synthetic oils. They test about the same for increased miles per gallon, although the range of results in different tests is very wide.

Both cost more than the regular oils, and the synthetics cost about twice as much as the other *improved* oils. Synthetics, however, are advertised for less-frequent oil changes (as much as 25,000 miles between changes).

If your car is still under warranty, check first with your dealer before choosing a synthetic oil or a less-frequent change interval.

Laboratory and road tests of the two types of oils give results ranging from small losses in fuel economy to improvements of nine percent. It is reasonable to expect an average improvement of about five percent, in combined city and highway driving, for both types of oil.

You'll have to do your own figuring to determine whether you're likely to save money as well as gasoline. It depends on how much you pay for the oil, and how often you have it changed.

Playing Our Tune

Tune-ups save gas. Right?

Right.

Tune-ups are expensive. Right?

Right again. You're not likely to save enough gasoline to pay for a full tune-up; but you need occasional tune-ups to keep your car running well, and increased gas mileage is an added benefit.

In many cases, a less expensive "minor" tune-up will yield significant gas savings. This means cleaning and regapping the plugs and points and adjusting the timing.

An evaluation from the Department of Transportation concluded that it is reasonable to expect a three percent average improvement right after a tune-up. The year-long improvement would be about one-and-one-half percent, because the tuned condition gradually deteriorates.

This means that the average driver, who spends $1,000 a year on gas, should save about $15 from an annual tune-up.

If you're willing to invest some dollars in hardware, there are a number of gauges and gadgets on the market that can help you help yourself to save gas. Tests show that the average driver is unlikely to save enough in gas to pay for some of them. But if you are above average in your determination to increase those miles-per-gallon, the gauges may pay for themselves. This is especially true if you can install the devices yourself.

Vacuum Gauges

A manifold vacuum gauge with a dial face, which can be used on or below the dash, measures the pressure in the engine intake manifold. It is a good indicator of the amount of fuel being consumed. Maintaining a high and steady vacuum pressure, as indicated on the gauge, can help you keep a light, steady foot on the accelerator when cruising. The gauge also indicates the benefits of decelerating versus braking. In tests, some drivers have increased their mileage by 24 percent using the gauge as a reference. But some other drivers actually got worse mileage, perhaps from watching the gauge instead of traffic.

In a fairly typical test at Georgia Tech involving five vehicles, improvements ranged from 8.5 percent to 13.6 percent.

If you're strongly motivated to improve mileage, the gauge can be a big help.

Miles-Per-Gallon Meters

Another more expensive gauge that's fun to use is the miles-per-gallon meter. It gives you continuous reading of the miles-per-gallon being obtained by your car. Mpg meters that add up the gasoline you use on each trip can be especially useful for figuring out the best routes, time of day to travel, and costs of short trips.

However, there are some limitations on many current models.

- There's usually a short delay in the meter's calculations. Your see what you were doing a few seconds ago rather than right now.
- In rapidly changing traffic conditions, the meter may be of little use. It won't remind you not to zip in and out of traffic.
- On the highway, the meter will show you convincingly that 40 miles-per-hour uses less gas than 55; but you already know that.

The meter could make for some lively conversation on a family trip, and it can be a good driver-education tool. You can decide for yourself whether it is worth the cost.

Automatic Cruise Control

A good way to avoid wasteful, uneven speeds when on the highway is to use cruise control. This device, purchased as original equipment or added on, holds your car to any speed you select when on the highway. It is deactivated at a touch of the brake. You can override it with the acelerator to drive faster, and on many models it returns to the pre-set speed when you remove your foot from the pedal.

The gas-saving advantage of cruise control is that it prevents unintentional speeding and variations in speed. You can set it at a steady 55, stop worrying about the highway patrol, and know that you are probably saving gas as well.

One disadvantage is that cruise control will maintain constant speed even up hills. For the greatest gas economy, you should strive for a constant accelerator pressure—rather than constant speed—when climbing. It is very simple to disengage cruise control when you start to climb and to reactivate it at the top of the hill.

Tests indicate that cruise control should improve gas mileage for the average driver by about five percent—or one mile per gallon if you're already getting 20 on trips. It is not used in city driving.

QUESTIONS

Fill in the chart with the advantages and disadvantages of some of the devices that you can add to your car to save fuel.

Device or Additive

1. New Motor Oil
2. Regular Tune-Ups
3. Vacuum Gauges
4. Mpg Meter
5. Automatic Cruise Control

Student Handout 14-3
How To Become An Inefficent Driver

Directions: Read each of the following rules. Write A if you agree with the rule. Write D if you disagree. Tell why you agree or disagree.

1. Always take off from a stop as fast as you can. You'll get where you want to go in less time, so you won't have to run your engine as long.
2. Use the cheapest gasoline you can buy. You'll get the same number of miles per gallon and more miles per dollar.
3. Don't bother to change your oil at recommended intervals: it'll just get dirty again anyway.
4. Only inflate your tires when you see that they are low: it's not worth the trouble to use a pressure gauge.
5. Leave your engine running during a short stop if the air conditioner or radio is on: you don't want to run the battery down.
6. Plan to make your trips during rush hour. Everyone else is on the road then, and you don't want to feel left out.
7. Always pack your car full of as many things as you can. You never know when you might need something, and then you won't have to make a trip back home for it.
8. Use your car especially for short trips because such trips don't use much gas.
9. Never turn off your engine while caught in a traffic jam: you will want to be able to start up right away when traffic gets moving again.
10. Look for short cuts to avoid traffic lights: this will avoid wasting gas while idling at the light.
11. Keep your foot on the gas as you approach a red light; it might turn green.
12. Plan to drive on slippery roads; there will be less friction, and less wear and tear on your car.
13. Always start the engine before planning your trips; this will give the engine plenty of time to warm up while you decide where you are going.
14. Don't buy milk and bread with your other groceries; they will be fresher if you make a separate trip to buy them when you need them.
15. Don't phone ahead to see whether friends will be home; they would rather be surprised by your visit.

Lesson 15

The Greenhouse Effect

Carbon dioxide (CO_2) has long-lasting and global effects on the Earth's climate. It is a stable compound that does not deteriorate in the atmosphere; therefore the compound and its effects will remain for a long time. CO_2 absorbs infrared radiation from the Earth's surface. This action prevents escape of solar energy, which warms the Earth's surface. In this lesson, students demonstrate both the CO_2 absorption of energy in the infrared range and the "greenhouse effect" produced in a closed container of glass or plastic.

OBJECTIVES

Students should be able to:

- Describe and give examples of the greenhouse effect as it applies to containers made of materials which allow the passage of visible light rays but not infrared (heat) rays.
- Relate CO_2's absorption of the Earth's infrared radiation to this greenhouse effect and the consequent warming of the Earth, comparing and contrasting this with what happens in an actual greenhouse.

TARGET AUDIENCE

Students of Chemistry, Physics, Earth Science, Physical Science

TIME ALLOTMENT

One and one-half class periods

MATERIALS

Two half-gallon jars
Plain water
Carbonated (seltzer) water
Incandescent light source
Two thermometers
Two rectangular heat-resistant glass baking dishes
A glass or plastic wrap cover for one of the dishes
Sunlight or an incandescent lamp
Student Handout 15-1, "Activity 2 Follow-Up"

BACKGROUND INFORMATION

The total solar energy intercepted by the Earth is estimated to be $174{,}000 \times 10^{12}$ watts, or 3.67×10^{21} calories, per day. To put it another way, the Sun sends 3.67 *quintillion* kilocals to Earth every day! If this heat were continually absorbed and never reradiated into space, the Earth would become too hot for survival. On the other hand, if the Sun's heat were *completely* lost back to space each night by reradiation, the Earth would be too cold for survival. Our atmosphere saves us from these fates.

The anticipated average temperature of the Earth, if it were influenced by no factors other than solar radiation and terrestrial reradiation, is only -19°C. However, our atmosphere acts as a blanket around us and raises the temperature to a very livable 12.5°C average for the globe. Approximately 50 percent of the solar energy that reaches the upper limits of the atmosphere reaches the surface of the Earth. The temperature of the northern hemisphere, where the atmosphere is drier, averages about 13.4°C, as compared to 11.6°C in the southern hemisphere. It is evident that the global average temperature is warmer than it would be if temperature depended only on radiation and reradiation.

The wavelengths of visible light range from the energetic, short violet waves, to the less energetic, long red waves. When matter absorbs solar radiation as light energy, it reradiates with the longer wavelengths of the infrared range as heat. Infrared radiation is less energetic, is reflected by glass or plastic, and is absorbed by water vapor and CO_2. We feel infrared radiation as heat when it is absorbed by an object or living matter.

As long as a body of matter is warmer than its surroundings, and as long as heat can escape from the matter, it will reradiate until equilibrium is reached. If heat is trapped by some form of insulation and cannot escape, however, the matter will become warmer and warmer. This principle is used to keep plants warm on cold days. A glass building allows the Sun's visible rays to penetrate to the inside (clear glass is transparent to the visible spectrum). The matter (including the plants) upon which these rays shine changes the high-energy radiation to low-energy radiation in the infrared range. As these rays are reradiated, they are reflected by the glass, which is opaque to infrared. The building retains heat even in cool weather, and the plants are saved from roasting or boiling only by mechanically opening the building to allow heat to escape. This type of arrangement for capturing the Sun's heat is called a greenhouse.

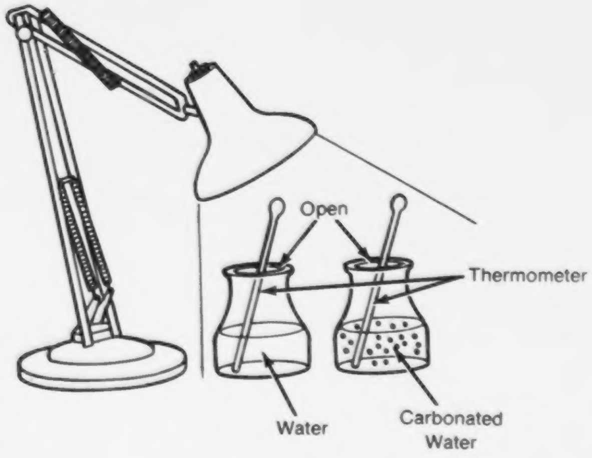
Two components of our atmosphere absorb heat reradiated from the Earth's surface: water vapor (H_2O) and carbon dioxide (CO_2). Researchers have pointed out that the heating effect of atmospheric water vapor is much less than that of CO_2, because the H_2O concentration decreases rapidly in the upper atmosphere. Yet there is another possible result from increased H_2O vapor—the cooling effect of increased cloud cover, which tends to minimize the CO_2 effect.

It is CO_2, however, that is the focus of research designed to predict climate changes which might result from the burning of fossil fuels and consequent release of CO_2. It is that problem which this lesson addresses, because researchers agree that the percent of CO_2 in the air has been steadily rising since the Industrial Revolution and has been producing a "greenhouse effect."

Activity 1

This activity demonstrates that CO_2 absorbs infrared radiation. If this can be shown, then it follows that radiation in the infrared range would tend not to escape the Earth's atmosphere, but, rather, would be trapped by it. Students should then deduce that the presence of CO_2 in the atmosphere would tend to trap heat (thermal radiation, i.e., infrared radiation), thus raising the average temperature of the Earth.

Place two half-gallon jars, one containing plain water, the other containing an equal amount of carbonated (seltzer) water, under a strong incandescent light source. The liquids should be at the same temperature. (Leave the carbonated water in the



original container until you are ready to start.) Tape a thermometer in each jar so that the bulb is just above the water level. Make sure each jar is the same distance from the light source. Turn on the light and, after an hour, read the temperature in each. Have students describe any other changes they see.

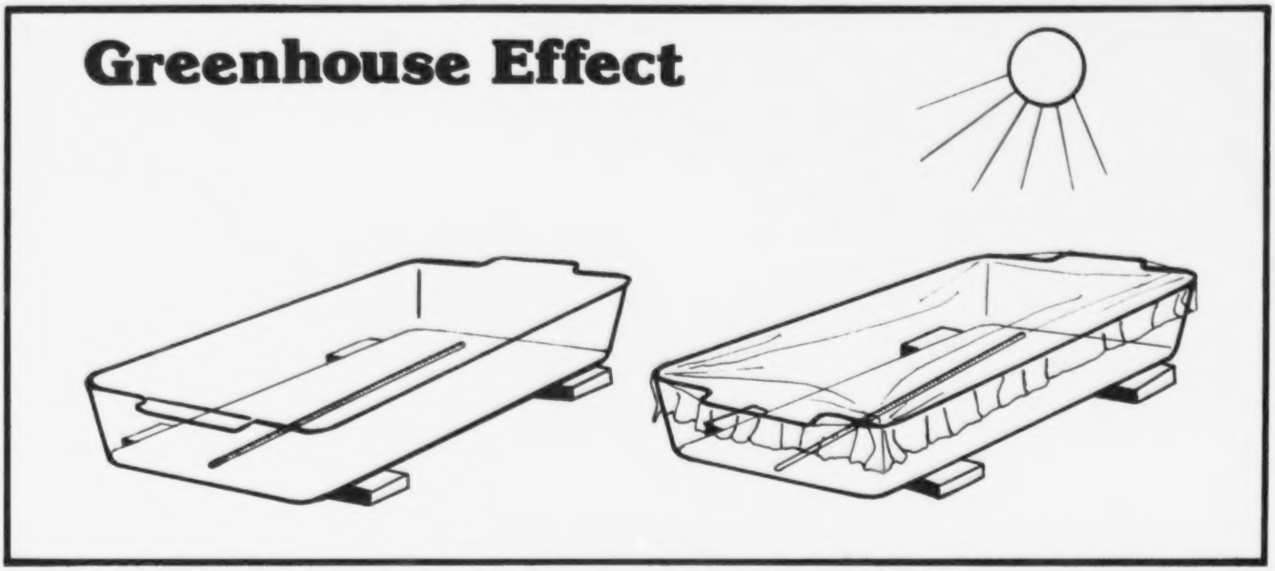
Activity 2

This activity demonstrates the greenhouse effect. If thermometers can be furnished to students, they may carry out the procedure at home; otherwise, groups may perform it during a class period. It is preferable to set dishes out in an area where they are exposed to the Sun, but if such an area is not available, an incandescent lamp may be used. (See illustration for method of setting up the equipment.)

If you are performing this activity in the classroom, set the dishes and thermometers out at the beginning of school so that they will all be the same temperature when the experiment begins. Remind students that an equilibrium temperature must be reached before the experiment can begin.

After equilibrium is reached, differential temperatures between the covered and uncovered dishes are quickly demonstrated. This should offer evidence to students that portions of incoming solar radiation can be changed to heat (infrared radiation) and trapped by certain agents. They should also be aware of the difference between the cause and effect in the greenhouse experiment and the cause and effect involved when CO_2 is the trapping agent.

After students have finished the experiment, they should be able to answer and discuss these follow-up questions.



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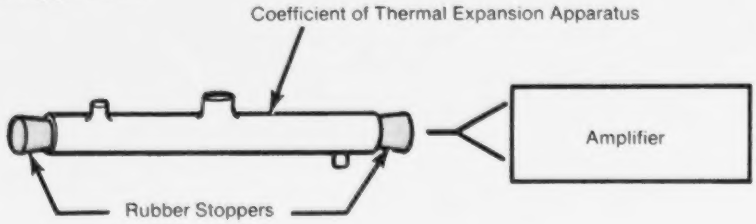
Norman, C. "Soft Technology, Hard Choices." *Worldwatch Paper* #21 (June 1978).

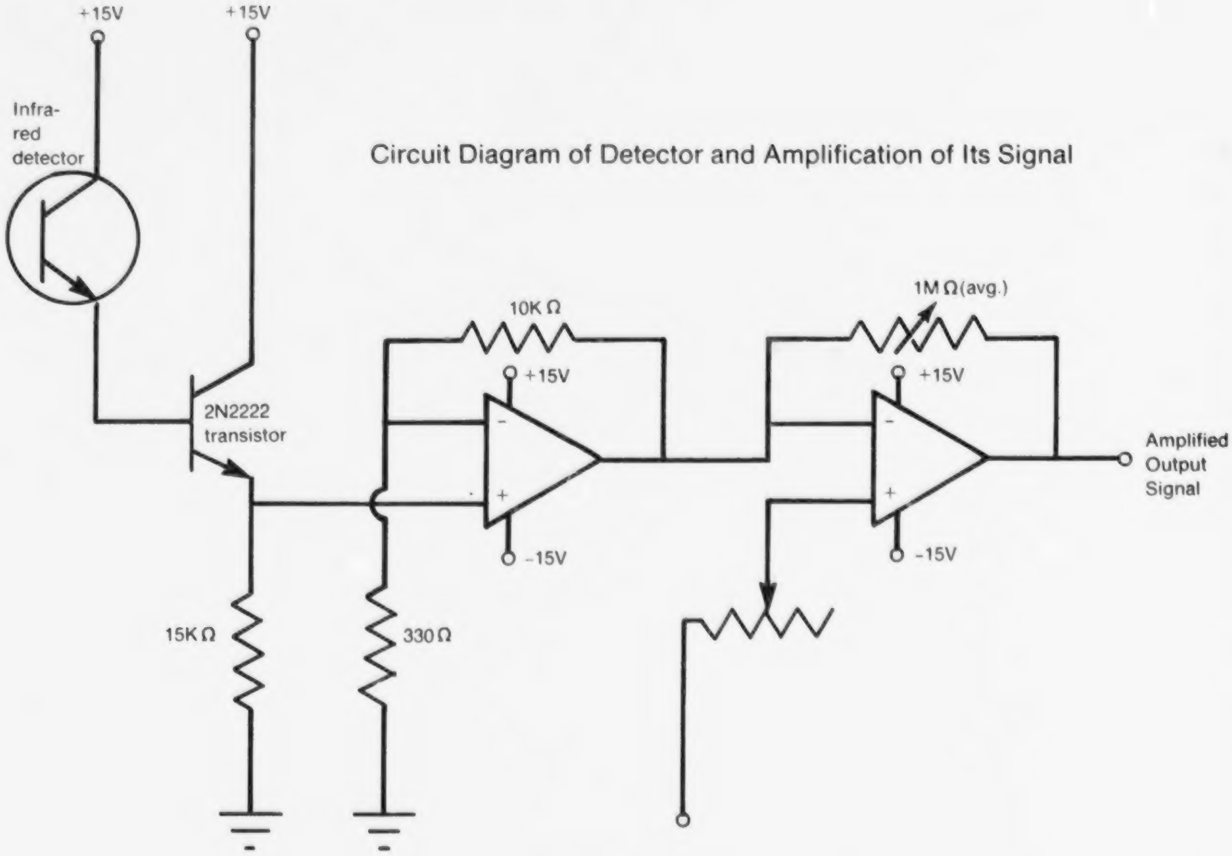
Sellers, W.D. *Physical Climatology.* Chicago Press: 1969.

Student Handout 15–1
Activity 2 Follow-Up

1. How was the solar radiation changed when it struck the baking dishes? (It was changed from the shorter waves and higher frequencies of visible light to the longer waves and lower frequencies of infrared radiation.)
2. Visible light was evidence of the short, high-frequency rays of solar energy. What was evidence of the presence of infrared radiation? (Accumulation of heat, as evidenced by the higher temperature in the "greenhouse," indicated trapped infrared radiation.)
3. The glass or plastic wrap *reflects* infrared light. In what two ways is this reflection different from the action of CO_2? (CO_2 *absorbs* the infrared radiation. And it *radiates* towards both space and the Earth.)
4. Where have you seen evidence of the greenhouse effect before? (Students will probably quickly respond with the effect of the sun on a closed car. They may also mention a warm area near a sunny window on a cool day. Lead them into a discussion of how this applies to the carbon dioxide

Drawing of Apparatus


Coefficient of Thermal Expansion Apparatus
Amplifier
Rubber Stoppers


Circuit Diagram of Detector and Amplification of Its Signal
+15V
+15V
Infra-red detector
2N2222 transistor
10K Ω
1M Ω(avg.)
+15V
+15V
-15V
-15V
15K Ω
330 Ω
Amplified Output Signal

level in the air, discussing the *possibility* of a global greenhouse effect.)

Extending the Lesson

Teachers with expertise in electronics may want to demonstrate the absorption of infrared radiation by CO_2 with the 276–142 infrared emitter and detector available from Radio Shack.

The emitter and detector can be mounted in rubber stoppers at the opposite ends of a coefficient of thermal expansion apparatus, as illustrated in the drawing. Possibly because of the length of the separation between emitter and detector, the detector signal may need to be amplified, as illustrated in the current diagram. A transistor amplifies the detector current, and two operation amplifiers amplify the voltage of this signal. An additional negative bias (minimum –15 volts) may be required on the second operational amplifier to eliminate spurious output signals when the detector is turned off. When the tube is filled with CO_2 by the insertion of a small chunk of dry ice, a reduction in the amplified output signal will be observed, but it is not dramatic.

Because the electronics is somewhat touchy, and more complicated than normally expected for high schools, this activity should be offered only to those so inclined. We would suggest that more ambitious researchers experiment with shorter distances between emitter and detector, in the hope of reducing the need for complex amplification. One suggestion would be a shortened cardboard tube. Glass or plastic might be undesirable because they admit infrared radiation from their surroundings.

Lesson 16

Global Temperature Changes and Possible Effects

This lesson emphasizes the global nature of, and the uncertainty about, the consequences of atmospheric warming from increased CO_2. The consequences of the greenhouse effect are described, and the scattering of light by the atmosphere (a cooling effect) is simulated.

OBJECTIVES

Students should be able to:

- Describe the consequences of increased CO_2 concentration.
- Apply these consequences to the area in which they live.
- Simulate the effects of clouds on sunlight.

TARGET AUDIENCE

Students of Chemistry, Physics, Environmental Science, Earth Science

TIME ALLOTMENT

Four to six class periods

MATERIALS

Student Handout 16–1, "The Variability of the Earth's Climate"
Student Handout 16–2, "The Scattering of Light"
Flashlight
Clear container of gelatin dessert

Activity 1

This activity emphasizes our uncertainty about the long-range and global consequences of increased CO_2 in the atmosphere and provides some illustrative examples. The final question in this activity is designed to stimulate students to think about how these long-range and global consequences could affect where they live. Have students read Student Handout 16–1. "The Variability of the Earth's Climate," and answer the questions.

Answers to Student Handout 16–1

1. Rising temperatures melt ice in the polar regions. The resulting water is added to the oceans and makes them higher.
2. Wisconsin.
3. Coastal areas would experience flooding; inland elevated areas would not be affected; the effect on both urban and rural areas must be considered.
4. Answers will vary, but the following gives an idea of what kind of answers to expect.

The impact of a temperature shift of that magnitude is difficult to predict, but it is likely to affect agriculture in many regions. It could, for example, push the American corn belt northward onto less fertile soils. But it could also extend the growing season in the Soviet grain-producing region and draw monsoon rains into higher latitudes, which would benefit China's rice cultivation. In general, global warming would bring increased rainfall, and probably cause local weather patterns to become more variable.

Activity 2

Student Handout 16–2, "The Scattering of Light," illustrates one source of our uncertainty about the magnitude of the temperature increase resulting from increased atmospheric CO_2. Warming of the atmosphere due to increased CO_2 increases evaporation and cloud formation. This in turn increases the diffusion of sunlight and thus, acts to cool the atmosphere in opposition to the "greenhouse effect."

The scattering of light by the fine particles in gelatin dessert simulates the scattering of light by particulate matter in the atmosphere. Probably the best-known example of particulate matter related to energy is the soot that arises from burning coal. Volcanoes also spew particulate matter into the atmosphere. (The eruption of Tambora in 1815 was followed by a 1° C temperature drop in the Alps and a cold, wet British summer in 1816.) Hence, man-made particulate emissions have been called the "human volcano."

Like clouds, particulate matter can reflect sunlight; and absorb sunlight as well. However, the residence time for these particles is fairly short-lived—from two days to two weeks in the lower troposphere, and from five to ten years in the mesophere (still relatively short). Thus, these particles do not produce long-range effects. Their effects can be global, however. (1)

Waste heat, another product of energy consumption, influences climate. The ratio of waste heat from energy consumption to solar radiation is very small: $9/174{,}000 = 5.17 \times 10^{-5}$. Thus, waste heat is not a *global* effect. It can, however, be significant at the local level. As is seen in the table of energy per unit area below, the waste heat produced in urban industrial areas approaches 10 percent of the radiation from the sun.

Comparison of Man-made and Some Natural Flows of Energy

Energy Flow	Rate (watts/ square meter)
Average solar radiation at earth's surface	approx. 170.00
Energy used to evaporate water, average rate	79.00
Average energy output of urban industrial areas	12.00
Average net photosynthetic production on land	0.13

Average heat flow from the interior of the earth	0.054
World use of energy (1970), distributed evenly over the continents	0.047
World use of energy (1970), distributed evenly over entire earth	0.013

This waste heat leads to the following local climatic effects in urban industrial areas.

Cloudiness
  5–10% more cloud cover
  100% more winter fog
  30% more summer fog

Precipitation (effect may be more pronounced downwind from urban area, at times)
  5–10% more (total)
  5% more snow

Relative humidity
  2% less (winter)
  8% less (summer)

Radiation striking surface
  15–20% less
  30% less ultraviolet in winter
  5% less ultraviolet in summer

Temperature
  0.5–1° C higher annual mean
  1–2° C higher winter minimum

Winds
  20–30% lower mean annual wind speed
  10–20% decrease in extreme gusts
  5–20% increase in calms

Source Carol and John Steinhart. *Energy: Source, Use, and Role in Human Affairs*, Duxbury Press, North Scituate, Massachusetts, 1974.

Have the students do the experiment and answer the questions in Student Handout 16–2, "The Scattering of Light."

Answers to Student Handout 16–2

1. They should see light coming from the gelatin dessert; particles in the gelatin dessert are scattering the light from the initial path of the flashlight beam.
2. They should not see any light coming from the water. The water contains no particles that scatter light. This demonstrates that the light-scattering particles in the gelatin dessert are from the gelatin powder and not from the water used to make the dessert.
3. No. Since the gelatin dessert scatters some of the light, not all of it passes through to the other side. This can be verified by using a light meter to compare the light intensity when the gelatin dessert is in the path of the light and when it is not.
4. Clouds scatter and reflect sunlight, thereby reducing the amount of incoming sunlight and its heating of the earth. This action opposes the greenhouse effect.

Discuss future prospects with the following guidelines in mind: Although the carbon dioxide content of the atmosphere has continued to increase, the earth has been cooling since the 1940's—0.2° C in the past 25 years. Some specific consequences of this cooling have been noted: England's growing season shrank 9–10 days from 1950 to 1966; occasional summer frost damages crops in the U.S. midwest; and sea ice has returned to Iceland's coast.

There are some indications that this cooling trend is ending: winters in the eastern U.S., Europe, and western U.S.S.R. were warm in 1973–75; and the southern hemisphere is warming to compensate for northern hemisphere cooling.

On the other hand, temperature patterns in Greenland in the past have led those in North America and Europe by about 250 years, and they suggest that colder weather is in store. Maybe the critical determinant is an increasing release of CO_2 into the atmosphere.

How can we know? The thrust of this lesson is that we can't, for sure. This is the main reason that more research and improved climate models are needed to predict the long-range and global effects of our fossil fuel combustion.

NOTES

1. R.A. Kerr, "Is the Arctic Haze Actually Industrial Smog?" *Science*, July 20, 1979, pp. 205, 209.
2. W.D. Sellers, *Physical Climatology*, Chicago Press, 1965, pp. 201–202.
3. Sellers, pp. 203–204.

SOURCES

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Student Handout 16–1
The Variability of the Earth's Climate

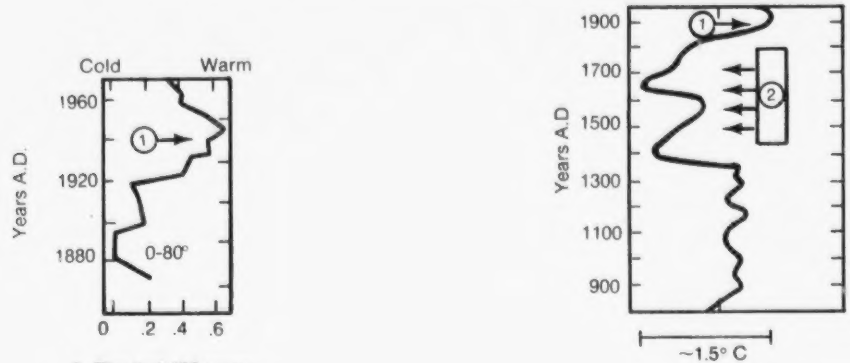
If fossil fuel consumption continues to increase at its present rate, the amount of CO_2 in the world's atmosphere is expected to double in 50 years. But we are uncertain in two ways about the effects of this doubling of CO_2:

1. We are uncertain about the temperature change that would result (an increase from 1° C to 5° C in the average world temperature has been projected).
2. We are uncertain about the effects of this temperature change on climate, technology sites, and food production in various regions of the world.

In order to reduce this uncertainty, meteorologists are currently attempting to construct consistent climate models that show the relationship between energy transformations involving the ground, the ocean, and the atmosphere. These models, based on relatively recent meteorologic measurements, should eventually lead to an understanding of the energetic interactions between the Earth's surface and the atmosphere, as well as between the polar and equatorial latitudes.

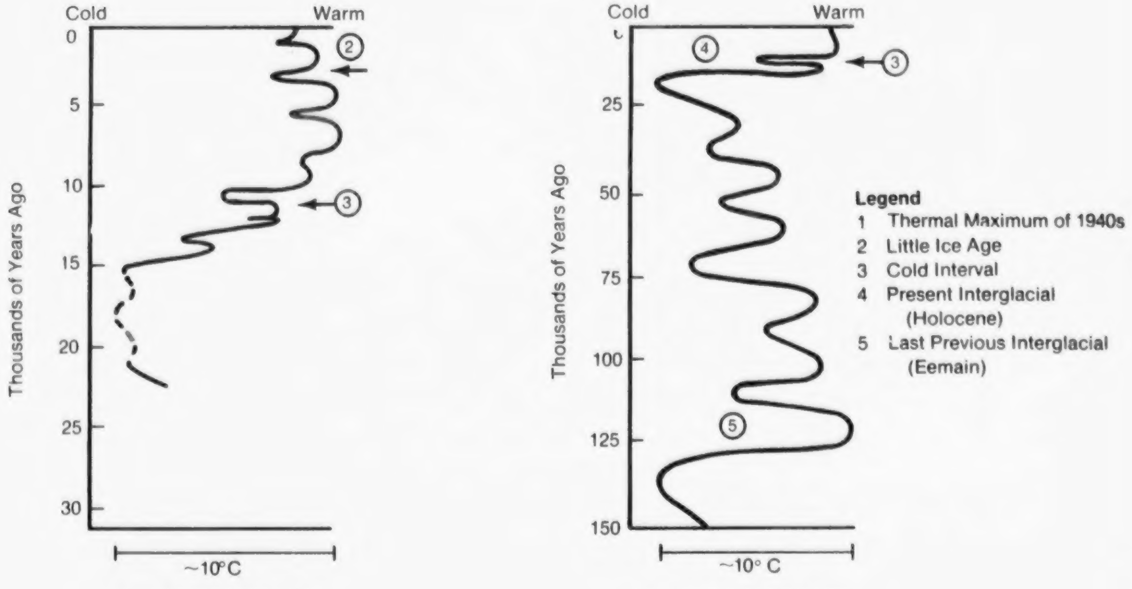
We can also learn about the effect of temperature change on climate from history. As shown in the following graphs, the Earth's average temperature has fluctuated considerably throughout the ages.

Midlatitude Air Temperature



A. The last 100 years

B. The last 1000 years



C. The last 10,000 years

D. The last 100,000 years

Generalized trends in global climate are represented by approximate surface temperature patterns that prevailed over a variety of time scales.

Consider the following descriptions of opposite temperature conditions in the Earth's past.

During the Eocene epoch (about 50 million years ago):

> Warm and moist conditions continued through the Eocene epoch. Both the average annual temperature in central Europe and the water surface temperature of the northern California coast in February were about 15° C higher than they are today. The hot summers and mild winters, particularly in high latitudes, precluded ice formation in any part of the world. Most of Europe enjoyed a typically Mediterranean climate, with the heaviest rains falling in winter. In England the climate was similar to that of a tropical rain forest. All of the United States was warm and wet, the eastern half of the country receiving annually about 180 cm of precipitation evenly distributed through the year. This climate produced luxuriant vegetation and abundant wildlife in regions that today are barren and unproductive. For example, palms, laurels, and magnolias were found in southeastern Alaska; spruce, pine, and willow in Grinnell Land, within 10° of the North Pole; and swamp forests in Tennessee. Alligators ranged as far north as Wyoming and the Dakotas. (2)

During the Pleistocene ice ages (beginning about one million years ago):

> . . . glaciation was worldwide. In the northern hemisphere, ice caps were most widely developed in North America, Greenland, and Scandinavia, with the North American ice cap being much larger than that in Europe. Approximately nine percent of the Earth's surface, or 30 percent of the land surface, was ice-covered at the peak of the ice ages, with glaciation occurring as far south as the White Mountains of Arizona. Only three percent of the Earth's surface is ice-covered today . . . The presence of cold-water fossils in the equatorial and subtropical seas suggests that the oceans were 5° to 10° cooler during the ice ages than during the interglacial ages. At the peak of glaciation, spruce forests covered Florida and Texas, reindeer and musk-oxen invaded the central United States, and walruses were found off the coast of Georgia. (3)

However, temperature is only one important factor in determining climate. Another is rainfall. As the Earth warms and cools, the mid-latitude arid regions (the Sahara, Gobi, and Mojave deserts in the north and the Australian desert and arid strips through South America and South Africa in the south) are expected to shift toward the poles during warming and toward the Equator during cooling. Such a shift is believed to be the cause of the dust bowl conditions in Oklahoma during the 1930's (the last decade of a warming trend that saw a 0.6 ° C average temperature increase since the Industrial Revolution). Consider John Steinbeck's description of this plight in the opening passages of his Pulitzer Prize winning novel, *The Grapes of Wrath:*

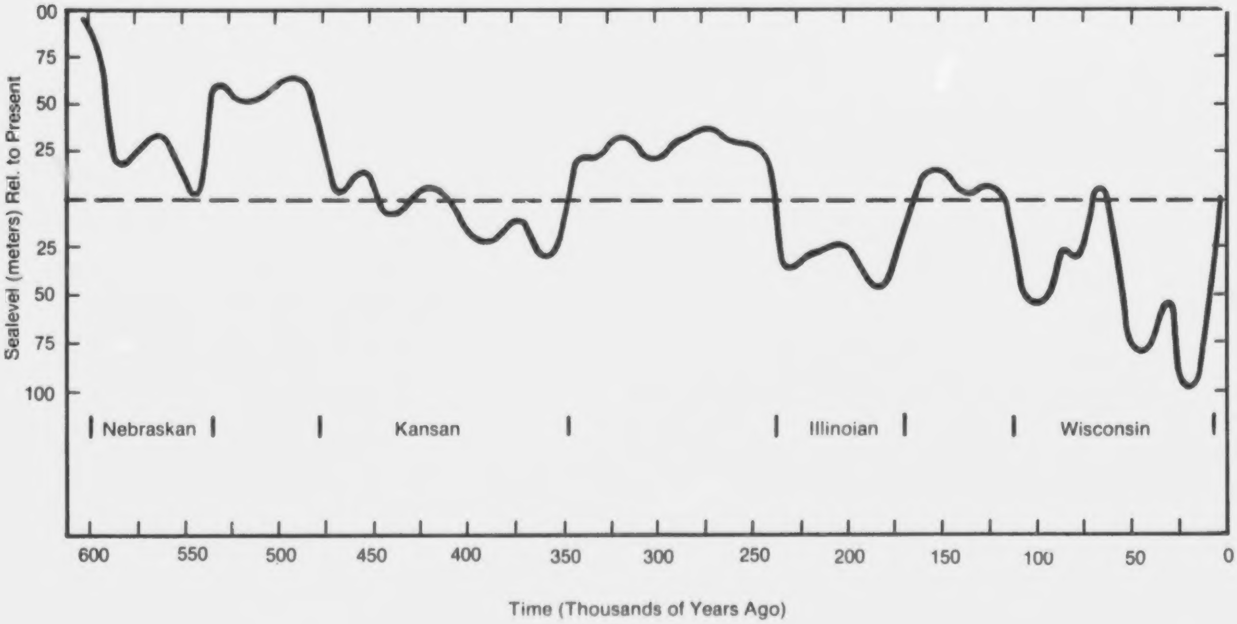
> To the red country and part of the gray country of Oklahoma the last rains came gently, and they did not cut the scarred earth. The plows crossed and recrossed the rivulet marks. The last rains lifted the corn quickly and scattered weed colonies and grass along the sides of the roads so that the gray country and the dark red country began to disappear under a green cover. In the last part of May the sky grew pale and the clouds that had hung in high puffs for so long in the spring were dissipated. The sun flared down on the growing corn day after day until a line of brown spread along the edge of each green bayonet. The clouds appeared, and went away, and in a while they did not try any more. The weeds grew darker green to protect themselves, and they did not spread any more. The surface of the earth crusted, a thin hard crust, and as the sky became pale, so the earth became pale, pink in the red country and white in the gray country.
>
> In the water-cut gullies, the earth dusted down in dry little streams. Gophers and ant lions started small avalanches. And as the sharp sun struck day after day, the leaves of the young corn became less stiff and erect; they bent in a curve at first, and then, as the central ribs of strength grew weak, each leaf tilted downward. Then it was June, and the sun shone more fiercely. The brown lines on the corn leaves widened and moved in on the central ribs. The weeds frayed and edged back toward their roots. The air was thin and the sky more pale; and every day the earth paled.
>
> In the roads where the teams moved, where the wheels milled the ground and the hooves of the horses beat the ground, the dirt crust broke and the dust formed. Every moving thing lifted the dust into the air: a walking man lifted a thin layer as high as his waist, and a wagon lifted the dust as high as the fence tops, and an automobile boiled a cloud behind it. The dust was long in settling back again.
>
> When June was half gone, the big clouds moved up out of Texas and the Gulf, high heavy clouds, rain-heads. The men in the fields looked up at the clouds and sniffed at them and held wet fingers up to sense the wind. And the horses were nervous while the clouds were up. The rain-heads dropped a little spattering and hurried on to some other country. Behind them the sky was pale again and the sun flared. In the dust there were drop craters where the rain had fallen, and there were clean splashes on the corn, and that was all.
>
> A gentle wind followed the rain clouds, driving them on northward, a wind that softly lashed the drying corn. A day went by and the wind increased, steady, unbroken by gusts. The dust from the roads fluffed up and spread out and fell on the weeds beside the fields, and fell into the fields a little way. Now the wind grew strong and hard and it worked at the rain crust in the corn fields. Little by little the sky was darkened by the mixing dust, and the wind fell over the earth, loosened the dust, and carried it away. The wind grew stronger. The rain crust broke and the dust lifted up out of the fields and drove gray plumes into the air like sluggish smoke. The corn threshed the wind and made a dry, rushing sound. The finest dust did not settle back to earth now, but disappeared into the darkening sky.
>
> The wind grew stronger, whisked under stones, carried up straws and old leaves, and even little clods, marking its course as it sailed across the fields. The air and the sky darkened and through them the sun shone redly, and there was a raw sting in the air. During a night the wind raced over the land, dug cunningly among the rootlets of the corn, and the corn fought the wind with its weakened leaves until the roots were freed by the prying wind and then each stalk settled wearily sideways toward the earth and pointed the direction of the wind.
>
> The dawn came, but no day. In the gray sky a red sun appeared, a dim red circle that gave a little light, like dusk; and as that day advanced, the dusk slipped back toward darkness, and the wind cried and whimpered over the fallen corn.
>
> Men and women huddled in their houses, and they tied handkerchiefs over their noses when they went out, and wore goggles to protect their eyes.
>
> When the night came again it was black night, for the stars could not pierce the dust to get down, and the window lights could not even spread beyond their own yards. Now the dust was evenly mixed with the air, an emulsion of dust and air. Houses were shut tight, and cloth wedged around doors and windows, but the dust came in so thinly that it could not be seen in the air, and it settled like pollen on the chairs and tables, on the dishes. The people brushed it from the door sills.*

(Note that the 15°C temperature rise during the Eocene epoch is much larger than the 0.6° increase noted above; during the Eocene epoch, the northern arid belt seems to have passed north of the continental United States.)

QUESTIONS

1. As the world's average temperature has risen and fallen, so has its sea level, as is shown in the graph below for the Pleistocene ice ages. Why would sea level rise and fall along with the world's average temperature?
2. Which of the four Pleistocene ice ages labeled on the graph was the coldest?
3. An increase of 6°C in average world temperature would increase sea level about 1 meter. What effect would this have on the area in which you live?
4. How would the climate where you live change if the world's average temperature increased by 1°C? Decreased by 1°C? By 5°C? (Find out the average temperature where you live, then find out the area directly north or south of you that has an average temperature higher or lower by 1°C or 5°C. Describe the climate of that area and compare it with the one in which you live.)

Note:* Bantam Books, Inc., 1954, pp. 1-2



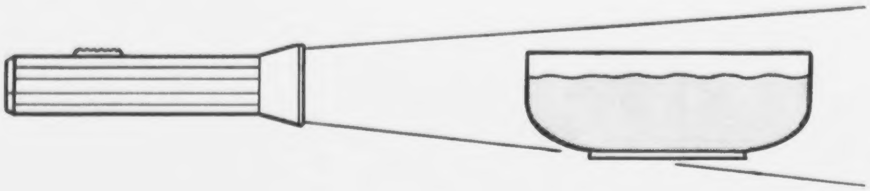
Student Handout 16-2
The Scattering of Light

Carbon dioxide warms the atmosphere by means of the greenhouse effect. The warming increases the evaporation of water into the atmosphere and the formation of clouds. This activity allows you to simulate the effect of clouds on sunlight.

Make a package of plain gelatin dessert in a clear glass container and let it jell. Then darken the room and shine a flashlight through the gelatin dessert. (The flashlight represents the sun, and the gelatin dessert represents the clouds.)

QUESTIONS

1. Look at the gelatin dessert from a direction perpendicular to the flashlight rays. What do you see?
2. Now shine the flashlight through a glass of water and look at the water from a direction perpendicular to the flashlight rays. What do you see?
3. Does as much light pass through the gelatin dessert onto the other side of the dish as originally came from the flashlight?
4. What does this tell you about the effect of clouds on sunlight?



Lesson 17

Use of Water in Coal Production

Water, that ubiquitous substance, is linked to coal at every step of the way from mine to power plant. Students are introduced to the coal-water relationship through a reading. They attempt to separate a coal slurry mixture, and review a case study on water quality, water availability, coal pipelines, and coal fields. The essay they write as a summary activity can serve as an evaluation of this lesson.

OBJECTIVES

Students should be able to:

- Describe water use during all phases of coal use—mining, transport, consumption, and mine reclamation.
- Name the possible effects of coal mining on water quality.
- Compare coal deposits and water use patterns in different parts of the U.S. to draw conclusions about potential coal/water problem areas.

TARGET AUDIENCE

Students of Chemistry, Earth Science, Environmental Science

TIME ALLOTMENT

Two to three class periods (Lab activity should continue at least three days, but need not take the entire period each day.)

MATERIALS

Student Handout 17-1, "Water and the Coal Resource"
Student Handout 17-2, "Coal Slurry Laboratory"
Student Handout 17-3, "Coal: A Case Study in Water Quality"
Coal (substitute charcoal if coal is not available)
Water
Hammer
Clear glass or plastic container (one per group)
Screens
Filter paper (various grades)
Evaporation dishes
Large container for water
Newspaper
Graduated cylinder
Distillation apparatus (optional)

TEACHING STRATEGIES

Introduce the topic by discussing the importance of coal as an energy resource. Your students may already know that coal is by far the greatest fossil fuel resource in the United States. You might ask the class about the advantages and disadvantages of increased coal use and list them on the board. Advantages: available; relatively low cost; allows more energy independence. Disadvantages: air and water pollution problems; land disturbance; increased demands for water.

Help students distinguish between two types of water use: withdrawal and consumption. Water withdrawal means simply that water is removed from the ground or diverted from a surface-water source for use. Water consumption refers to water that is no longer available because it has been evaporated, transpired, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the immediate water environment.

Now distribute Student Handout 17-1, "Water and the Coal Resource." Have students read the introduction and look at the data table. Discuss the questions with them in class.

Answers to Student Handout 17-1

1. Power generation.
2. Coal slurry: water travels from source and is no longer available for use. Mining: evaporates. Reclamation: becomes ground water.
3. Rail.
4. Power generation plant. There are several alternative cooling schemes (air cooling or cooling ponds, for example).
5. a) They would be built close to water resources instead of close to mines.
   b) Slurry pipelines would be much less feasible.
   c) Coal would be cleaned closer to place of use, rather than at mine, if water situation were better.
6. Power generation, according to the table.

Next, proceed to the laboratory activity. Before beginning this activity with the class, use a hammer to break up the coal into fairly small pieces. Work on newspaper. Pour all pieces, large and small, into a container of water. Mix well. This should produce a material that resembles what is found in a coal slurry pipeline. Now distribute Student Handout 17-2 "Coal Slurry Laboratory," and divide the class into groups of four or less. Give each group the same volume of the coal water mixture, and go through the lab procedure with them. Have on hand the suggested materials, and let each group plan its own method of attack. Most will begin by filtering. From this point strategies may vary, but students are likely to try settling, evaporation, additional filtering, and/or distillation. Give students ample time over several days to complete the task. Make comparisons as noted on the student pages.

At the conclusion of the laboratory activity, discuss the following questions.

1. What was your major difficulty? (Separating the smallest particles of coal from the water.)
2. What difference does it make at the end of a coal slurry pipeline if the fine particles cannot be separated out? (Limits the future uses of that water; loses some of the fuel value of the coal that was put into the pipeline.)
3. At what step(s) in your procedure was water lost and how could you have prevented those losses? (Answers will vary.)
4. Besides the presence of coal particles, how would you determine whether or not water quality had been affected in other ways by making the coal slurry?
5. What have you learned about coal slurry pipelines through this activity? (A coal slurry pipeline requires significant amounts of water; it is difficult to separate all of the coal from the water at the end of the pipeline; and water quality is

affected by mixing coal with water.)

You may conclude this activity by listing the advantages and disadvantages of coal slurry pipelines with the class. *Advantages:* causes less air and noise pollution because it is built underground; makes possible more direct routing over difficult terrain; less expensive than rail, and useful if rail could not handle coal. *Disadvantages:* large water requirements at mine mouth; service limited to one point of origin and one destination; effluent problems at destination; coal must be processed at both ends of the line.

Next, distribute Student Handout 17-3, "Coal: A Case Study in Water Quality." Let students read the case study on surface mining and water, and look at the map of coal resources, the chart of water problem areas, and the map of coal slurry pipelines. To complete the lesson, students should write an essay covering the points listed on their summary sheets. (If you do not wish to use the essay format, simply change the essay points into individual questions for the students.)

As you evaluate the essays, look for coverage of all the points in a manner consistent with the data students have been given. Some of the specific points are noted below.

Water is used in mining to control dust and clean coal; it is used in slurry pipelines; it is used to reclaim land; and to cool power plants in which coal is burned.

The greatest *quantities* of water are used in slurry pipelines and in coal-burning power plants.

Water quality can be a major problem at a mine site. Acids, alkalis, suspended and dissolved particles, and metals can pollute water draining from the site. Mining can interfere with water tables and aquifers.

Water allocations in the lower Colorado and Rio Grande basins will have to be planned carefully because the coal resources in these areas are much greater than the amount of water available for use in resource production.

Possible solutions include more efficient use of water, use of coal to generate electricity *away* from areas of high competition for water, and transport of water from other basins into areas where it will be needed for coal development.

Student Handout 17–1
Water and the Coal Resource

Coal mining, processing, and consumption cannot take place without water. At the mine, water is used to suppress dust and to reclaim the land after strip mining. Coal is washed with water to remove impurities like ash and sulfur. Coal can be transported in water: it is pulverized, mixed with water, and pumped through a coal slurry pipeline over great distances. At its destination, the coal must, of course, be dewatered and dried before it can be burned.

None of these processes, however, takes as much water as a coal-fired electric power plant. There the coal is burned to heat water and produce steam by which electricity is generated. Large amounts of water are needed to cool the steam.

Use the table to answer the questions below:

1. The water requirements listed in the table are actually amounts of water withdrawal. In which process(es) is little of the water withdrawn likely to be consumed?
2. In which process(es) is much of the water likely to be consumed?
3. Besides slurry pipeline, what other major means are used to transport coal from western sites?
4. In which process do the water quality problems seem most easily solved?
5. If water resources are more scarce in the West, Southwest, and Midwest, how will that influence:
   a) location of power generating plants?
   b) transportation of coal from the mine?
   c) location of coal cleaning facilities?
6. In which process do the potential savings in water use seem greatest?

Water Requirements in Coal Development and Use

Process	**Requirements (gal/million Btu)**	**Water Use**	**Quality Problems**
Western Coal Mining	0.25–0.61	dust control washing	acid/alkaline drainage dissolved & suspended solids metals
Surface Mine* Reclamation	0.38–3.0	watering vegetation	none
Eastern Coal Mining	0.66–0.75	dust control washing	acid drainage dissolved & suspended solids metals
Coal Slurry Pipeline	10.1	transport fluid	dissolved & suspended solids metals
Power Generation	120.16	steam generation cooling	thermal

*data for one mine only, in Wyoming

Sources: *The Nation's Water Resources. The Second National Assessment,* Part II, U.S. Water Resources Council, 1978, p. 132.

Environmental Data for Energy Technology Policy Analysis, Vol. I: Summary, Mitre Corporation, Jan. 1979.

Student Handout 17–2
Coal Slurry Laboratory

The problem of transporting coal from the mine to its destination is becoming increasingly important. Advocates of coal slurry pipelines say pipelines are needed for two reasons: the railroad may not be able to handle the increase in western coal traffic predicted for the future; and the cost of transportation by slurry may be significantly lower. To prepare the coal for slurry transport, the coal is crushed at the mine, water is added, and the coal and water mixture is pumped through the pipeline to its destination.

Although this method of transportation is efficient and may be cheaper than rail, the pipelines require enormous amounts of water at the point of shipment—a key problem in arid western coal fields. It is estimated that about one ton of water is needed for each ton of coal moved. A pipeline moving 25 million tons of coal annually requires about 15,000 acre/ feet of water per year at its source. (An acre/foot is 1,233,531 liters, or 329,613 gal.) Disposing of the pipeline effluent at the end of the line is also a problem.

In this laboratory activity you will investigate the problems of a coal slurry pipeline. Specifically, you must separate the coal from the water to make the water as clean as possible.

1. Get the coal slurry mixture from your teacher.
2. Measure its total volume.
3. Using the materials made available to you, separate as much coal from the water as you are able.
4. Be sure to record each strategy you undertake. For each one, note steps you take, the time used, any energy input outside of yourselves, and any comments you care to make on the process.
5. Save *all* water and coal. *Do not* dispose of *any* amount of either.
6. When finished, compare your results with other groups in class in these ways: color of water remaining; amount of water saved (withdrawn, but not consumed); time and nonhuman energy input.

7. When all of the above has been completed, add the coal back to the water and measure its total volume again. Subtract from the original volume to calculate how much water has been consumed.

Student Handout 17-3
Coal: A Case Study in Water Quality

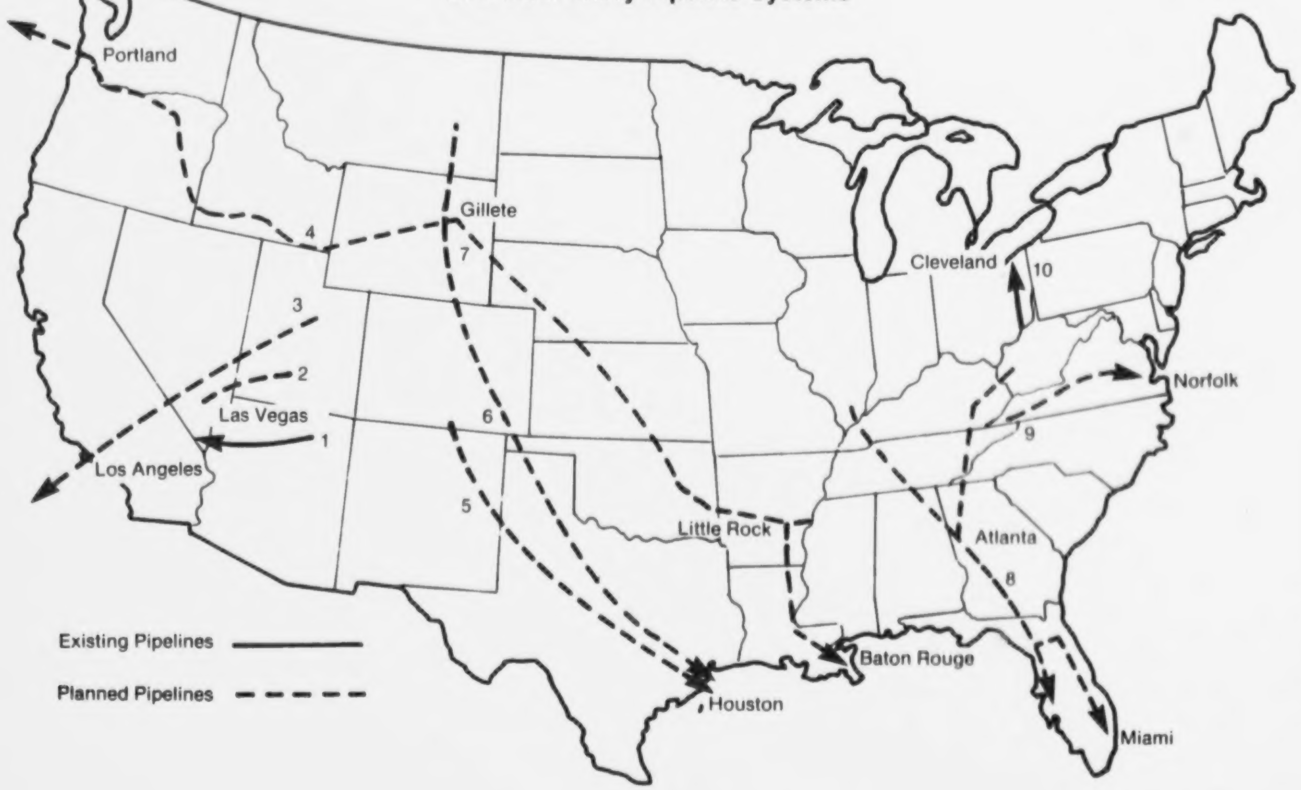
Many strippable coal beds in the West are near or underlie surface drainage channels and underground waterways of permeable rock called aquifers. Underground and surface mining of their coal could have serious impacts, significantly disrupting the West's fragile hydrologic system and causing serious secondary effects.

During surface mining, for instance, natural drainage channels are often diverted to facilitate coal extraction. Diversion channels are usually constructed of easily erodable soil and, during heavy rains, streams and waterways are often polluted by the channels' erosion, affecting both plant and fish life. In addition, underground mining can contaminate usable aquifers that support human, animal, and plant life with salts and other minerals. In many cases, there is no alternative source of water, so an already limited ground water supply is further reduced.

Of special interest in the West is the preservation of alluvial valleyfloors, that is, downstream valleys fed by or near surface streams. These valleys are the productive lands for agriculture and cattle ranching in the West. Mining in or near these areas can disrupt drainage patterns, which interrupts the recharging of

Pipeline System	Length (Miles)	Annual Capacity (Tons)
1. Black Mesa	273	4,800,000
2. Allen-Warner Valley	183	11,600,000
3. Pacific Bulk	650	10,000,000
4. NICES	1,100	25,000,000
5. San Marco	900	10,000,000
6. Texas Eastern	1,260	22,000,000
7. ETSI	1,387	25,000,000
8. Coalstream	1,500	25-55,000,000
9. VEPCO	350	5,000,000
10. Ohio	108	1,300,000

U.S. Coal Slurry Pipeline Systems



the alluvial floors and reduces the valley's productivity. Surface mining legislation is needed to help protect these valleys. (1)

The case study below will give you some idea of the water problems in an area near a particular strip mine. Although the names have been changed, this is an actual history.

Blue Valley Coal Mine has attempted to keep all the water it uses on the mine site instead of discharging it. To accomplish this task, Blue Valley has built holding ponds from which the water is allowed to evaporate. The water also is sprayed on dusty roads. There have been some problems with the ponds. For example, one pond was undersized and discharged onto land around the mine site, and a drainage ditch once discharged directly into Azure Creek. These problems are being corrected.

Azure Creek has come under some scrutiny because at one time it was a seasonal watercourse, only flowing at certain times of the year. It now flows year-round. Area residents believe that the mine's holding ponds, a water pond for cooling the coal power plant, and a new sewage system nearby have caused this change.

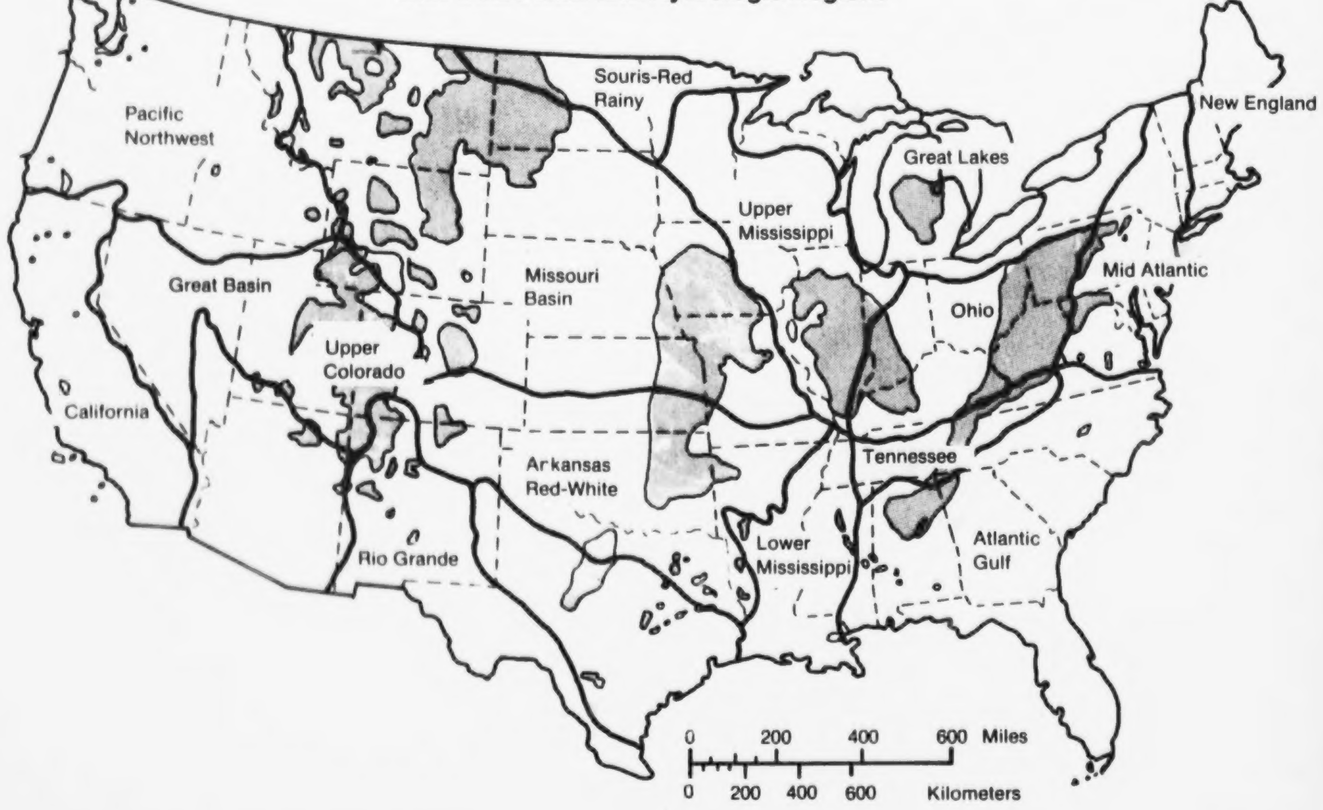
On a nearby ranch, the Appel family blames its loss of high quality well water on leakage from Blue Valley's mine site into Rabbit Creek, which feeds the local underground water supply. Their well water has become dark, salty, and unusable. They have had to drill a new well, and have filed suit against Blue Valley Mine.

The company has been cited for being insensitive to the groundwater needs of local ranchers. For example, there is a 25-foot coal seam considered by residents and the Bureau of Land Management to be a critical local aquifer for households and livestock. However, Blue Valley has said that the coal seam is "very disrupted and an unreliable groundwater source. It has little economic importance since its use is only supplemental." This coal seam runs through the mine site. Replacement of portions of this seam with spoils (mining leftovers such as shale, clay, and sand) has altered the water pathway, and fields to the north of the mine have been flooded by rising water tables.

Finally, Blue Valley has been warned that the overburden they are grading in reclaimed areas is extremely salty. This work could also affect groundwater quality. (2)

Source: C.E. Gagge, "Issue in Brief: The Case for Coal Slurry Pipelines," National Coal Association.

U.S. Coal Fields and Hydrologic Regions


Souris-Red
Rainy
New England
Pacific
Northwest
Great Lakes
Upper
Mississippi
Mid Atlantic
Great Basin
Missouri
Basin
Ohio
Upper
Colorado
California
Tennessee
Arkansas
Red-White
Lower
Mississippi
Atlantic
Gulf
Rio Grande
0 200 400 600 Miles
0 200 400 600
Kilometers

Regional Runoff and Consumption Stastistics for 1975*

Region	Mean Annual Runoff (millions of acre-feet per year)	Data for 1975		
		Consumption (millions of acre-feet per year)	Per Capita Runoff (acre-feet per person per year)	Consumption as a Fraction of Mean Annual Runoff
New England	75.3	0.49	6.40	0.0066
Mid-Atlantic	97.2	1.78	2.43	0.018
South Atlantic Gulf	218.7	4.13	8.26	0.019
Great Lakes	81.0	1.22	3.65	0.015
Ohio	137.7	1.38	6.48	0.01
Tennessee	46.2	0.32	13.77	0.0068
Upper Mississippi	72.9	1.05	3.73	0.014
Lower Mississippi	81.0	6.16	13.77	0.069
Souris-Red Rainy	7.0	0.14	9.72	0.016
Missouri	60.8	19.44	6.80	0.32
Arkansas	81.0	12.96	12.96	0.16
Texas Gulf	35.6	10.53	3.40	0.30
Rio Grande	5.6	4.86	2.84	0.87
Upper Colorado	14.6	2.75	32.40	0.19
Lower Colorado	3.6	8.10	1.38	2.3
Great Basin	8.	4.46	5.67	0.55
Pacific Northwest	234.9	14.58	35.64	0.062
California	69.7	27.54	3.32	0.40
Alaska	648.0	0.0062	1620.00	9.6×10^{-6}
Hawaii	14.6	0.62	17.82	0.043
United States	2001.5	122.31	8.91	0.060
United States excluding Alaska and Hawaii	1338.9	121.50	6.32	0.091

* Totals may not add due to rounding (p. 199 CONAES Report)

Source: *Energy in Transition* 1985–2010. Final Report of the Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences, 1979.

Using what you have learned about coal and water, look over the preceding maps and tables and write an essay that covers the following points:

- Ways in which water is used in all phases of coal development from mining to burning.
- The point(s) at which the greatest *quantities* of water are required in coal development and use.
- How and where in the process of coal production water quality is a problem.
- Which areas of the United States will have to plan their coal development and water resource allocations carefully, given increased coal development in this country.
- Some suggestions for minimizing water quantity and quality problems associated with coal.

Remember to support your statements.

Notes

1. *U.S. Coal Development—Promise, Uncertainties*, Report to Congress, Comptroller General of the United States, September, 1977.
2. D.P. Wiener, *Reclaiming the West*, New York: INFORM Books, 1980.

Lesson 18

Use of Water in Oil Shale Production

The energy potential of oil shale is great. However, there are many obstacles to its development, one of which is water availability. This lesson investigates some of the projected water requirements of an oil shale industry in the semi-arid regions of the west where the largest, richest deposits of oil shale are located.

OBJECTIVES

Students should be able to:

- Calculate water requirements to mine and process shale and reclaim the site.
- Explain the limits to oil shale development in the Colorado River Basin by comparing projected water needs with annual runoff carried by that river.

TARGET AUDIENCE

Students of Earth Science, Environmental Science, Physical Science

TIME ALLOTMENT

One to two class periods

MATERIALS

Student Handout 18-1, "Oil Shale"
Calculators (optional)

TEACHING STRATEGIES

Distribute Student Handout 18-1, "Oil Shale." Have students read the overview, study the chart, and answer the questions that follow.

Answers to Student Questions

1. Surface: $4.5 + 34.6 + 41.1 = 80.2$ gal/ton
   In situ: $4.5 + 34.6 + 17.8 = 56.9$ gal/ton
2. Surface: $(0.4) \times 80.2 = 3.2$ gal water/gal shale oil
   In situ: $(0.4) \times 56.9 = 2.3$ gal water/gal shale oil
3. 100,000 bbl/day for one day
   Surface: $7.6 + 58.1 + 69.0 = 134.7$ gal $\times 10^5$
   In Situ: $7.6 + 58.1 + 29.9 = 95.6$ gal $\times 10^5$
   100,000 bbl/day for one year
   Surface: $(134.7 \times 10^5) \times 365 = 4916.6 \times 10^6$
   In Situ: $(95.6 \times 10^5) \times 365 = 3489.4 \times 10^6$
4. 1.68 tons/barrel $\times 10^5$ barrels $= 1.68 \times 10^5$ tons shale.
5. a. 1.68×10^7 barrels $= 3.024 \times 10^7$ tons/day
   $3.024 \times 10^7 \times 365 = 1.104 \times 10^{10}$ tons/year
   b. 95.6 gal $\times 1.8 \times 10^7$ bbls $= 1.72 \times 10^9$ gal water/day
   or 56.9 gal/ton $\times 3.024 \times 10^7$ tons/day
   $= \quad 1.72 \times 10^9$ gal water/day
6. a. $\dfrac{1.35 \times 10^7 \text{ gal/day consumed}}{1.3 \times 10^{10} \text{ gal/day available}} = 1.04 \times 10^{-3}$

   $1.04 \times 10^{-3} = .0001038$
   $.01038 = 0.1\%$

   b. In approximately 20 years.
7. No, it is not reasonable. An industry output of 51,200,000 barrels/day requires more than half of the Colorado River's runoff. Note: To be considered in this context is the fact that the Colorado River is one of the most highly controlled rivers in the world. No less than seven states and the Republic of Mexico draw upon the water of the Colorado River, which is governed by ten major "Laws of the River." To the energy production demands placed upon the river must be added growing urban demands for industrial and residential water, irrigation and agricultural uses, coal, uranium, and related energy develoment, and recreation and scenic requirements. Clearly, total water management embracing both quantity and quality must be incorporated if current and future demands are to be met.

Student Handout 18–1
Oil Shale

Traditionally, oil is pumped from the ground, but it can be mined as well. There are places on earth where the eons-long process of deposition and decay of organic material (typically at the bottom of seas or lakes) was not accompanied by enough heat and pressure to produce oil or natural gas. What is left as a result are rich deposits of solid hydrocarbons. The most familiar and potentially useful of these are the oil shales and tar sands. In oil shale, a heavy complex hydrocarbon, *kerogen*, is mixed in with the rock. Rocks with a high kerogen content can even be burned.

There are three methods of recovering oil from shale that are currently being investigated: surface retorting, in situ retorting, and modified in situ retorting. A retort is a chimney-like column in which shale fragments are heated to vaporize the oil. The vapor is then cooled and condensed for collection. All three methods use the retort, but in different ways. Surface retorting involves mining the shale, crushing it, and processing it in free-standing retorts. In situ retorting takes place underground, where a columnar space is blasted out of the earth and the shale rubble thus created is heated where it is. A newer process, called modified in situ retorting, requires mining 20–25 percent of the rock at a particular site, creating retorts as it goes. Then the oil is extracted in place.

As liquid oil becomes less abundant and more expensive, the solid oils in oil shale and tar sands begin to look attractive. Tar sands are being processed in Canada, but oil shale development is not being pushed in this country primarily because it is still more expensive than petroleum. These solid oils have both advantages and disadvantages.

Advantages: The major advantage of both oil shale and tar sand is the size of the resource. The reasonably accessible oil shale equals the conventional oil resources of the U.S., and the tar sand potential of Canada is much larger than that country's oil resource. They are both domestic resources whose development would produce jobs and taxes in the U.S. and reduce the balance of payments deficit.

Advantages: Oil shale and tar sands share the somewhat dubious advantage of nuclear energy and coal synthetics. The capital cost of construction is so high that the fuel costs are a relatively small percentage of the total. The resource reservoir is also quite large. The final cost of the synthetic fuel, therefore, should not show the year by year escalation in price characteristic of a depleting resource.

Disadvantages: At present the major disadvantage is economic. The large capital investment and other costs result in an oil that just barely competes with present OPEC prices. There are also serious environmental and social costs. Waste disposal for oil shale production will use up much land and threaten scarce western water supplies, not only by direct use of water, but by disturbance of local aquifers. Air pollution is also a potential problem, as are water pollution from leaching, and disturbed land.

Equally serious is the lack of water for processing plants and the associated industries and boom towns. The social costs of the boom town cycle concern current residents of potential mining areas. Turning to oil shale will commit the country to a huge mining effort in what has been until now largely park land, so there will also be an aesthetic price to pay.

It does not seem likely that oil shale will compete on a purely marketplace basis for a decade or so. If the country wants the oil from the Colorado Mountains it must pay extra for it. The payment will take the form of federal guarantees and perhaps tax credits. It is also likely that some indirect payments in the form of air pollution easements, water reallocation, etc. will be needed. The resource is there, and the needs and priorities of the eighties will decide its fate. See the table below.

1. How many gallons of water are required to mine, convert, and reclaim 1 ton of shale yielding 25 gallons of shale oil?
2. Determine the water requirements to produce 1 gallon of shale oil.
3. Current technology suggests that a plant producing 100,000 barrels of shale oil per day might be feasible. Calculate the daily and annual water requirements for such a plant.
4. How much shale would need to be processed to yield 100,000 barrels of shale oil?
5. Suppose that the current U.S. consumption of oil is 18 million barrels/day. Further suppose that a full scale oil shale industry could be developed in this country to supply the total U.S. oil requirements.
   a. How much shale would need to be processed daily? Yearly?
   b. What would be the daily water requirements for mining, converting, and reclaiming the land, assuming in situ techniques are used?

Water Requirements for the Oil Shale Industry

			WATER REQUIREMENTS			
					Reclamation	
This Much Shale	Yields This Much Oil	Which Yields This Much Energy	Mining	Conversion	Surface	In Situ
1 ton	25 gallons	3.36×10^6 Btu 3.54×10^9 joules 9.84×10^2 kWh	4.5 gal.	34.6 gal.	41.1 gal.	17.8 gal.
1.68 tons	1 barrel	5.64×10^6 Btu 5.95×10^9 joules 1.65×10^3 kWh	7.6 gal.	58.1 gal.	69 gal.	29.9 gal.

6. The richest oil shale is located in the Piceance Basin of Colorado, Utah, and Wyoming, a hydrologic region called the Upper Colorado River Drainage. Records indicate that the average runoff carried by the Colorado River in this region is 13 billion gallons/day (1.3×10^{10} gal/day). The oil shale industry will draw upon the Colorado River and its tributaries to supply its water needs.
   a. What portion of the river's average daily flow would a 100,000 barrels/day surface oil shale industry consume?
   b. If the oil shale industry doubled its output every two years, in how many years would the water requirements of the industry consume about 75 percent of the Colorado River's runoff yearly? (Assume an initial industry output of 100,000 barrels/day.)
7. Considering the results of the preceding question, would it be reasonable to assume that shale oil will replace a significant portion of the U.S. daily requirements? Explain.

Industry Output (Barrels/Day)	Years	Industry Daily Consumption (Gal.)	River Daily Runoff (Gal./Day)	Runoff Consumed (Per Day)
0	0		1.3×10^{10}	0
1×10^5	2	1.35×10^7	"	.00104
2×10^5	4	2.70×10^7	"	.00208
4×10^5	6	5.40×10^7	"	.00415
8×10^5	8	1.08×10^8	"	.00831
1.6×10^6	10	2.16×10^8	"	.0166
3.2×10^6	12	4.32×10^8	"	.0332
6.4×10^6	14	8.64×10^8	"	.0665
1.28×10^7	16	1.73×10^9	"	.1329
2.56×10^7	18	3.46×10^9	"	.2658
5.12×10^7	20	6.92×10^9	"	.5317
1.02×10^8	22	1.38×10^{10}	"	1.0633

Lesson 19

Use of Water in Thermoelectric Power Plants

By far the largest water user among the energy industries is the thermoelectric power plant. Through a lab activity, reading, diagrams, and tables, students investigate water withdrawal, thermal pollution, and the various technical methods available for cooling water before it is returned to its source. Students also examine the factors that determine the choice of technologies used in the cooling system of a particular generating plant.

OBJECTIVES

Students should be able to:

- Discuss uses of water in thermoelectric power plant operation.
- State the effects of heating on aquatic ecosystems.
- Compare the various cooling systems in power plants in terms of relative water consumption, thermal pollution, atmospheric changes, and cost.
- Compare projected increases in water demands with the amount of runoff available for use from rivers and streams.

TARGET AUDIENCE

Students of Earth Science, Environmental Science, Physical Science

TIME ALLOTMENT

One to three class periods

MATERIALS

Student Handout 19-1, "Thermoelectric Power Production and Water"
Thermometers (0–100° C)
Food coloring
Hot water
500-ml beakers
Larger beakers or containers (1000 ml)
Pans and trays of various sizes
Lengths of plastic tubing

BACKGROUND INFORMATION

More than 90 percent of the water used in offstream energy production is used to cool thermoelectric (fossil fuel and nuclear) power plants. In the past, most of the cooling was done by withdrawing water from a river or other source, running it through the power plant, and returning it to the source at whatever temperature it left the plant. This is called once-through cooling.

However, returning hot water to a cooler body of water, thermal pollution, was recognized as a threat to aquatic ecosystems. Various technical methods of cooling the hot water now have been developed and are in use at thermoelectric power plants. These include the use of cooling ponds, wet towers, and dry towers.

If electricity demand increases in the future, more of these technologies will have to be employed to insure that returning the water to the environment neither causes pollution nor precludes other uses.

Additional background is found in the student section.

TEACHING STRATEGIES

Begin with the following laboratory experiment. Heat a large volume (2–2½ L) of water to 80°C and add several drops of food coloring. Give each group of four students 300 ml of this hot colored water in a 500 ml pyrex beaker. Tell them that the purpose of this activity is to lower the temperature of the water as much as possible without adding anything directly to the water or decreasing the volume of water appreciably. They also cannot use ice in any manner.

Make available trays, lengths of tubing, and larger beakers. Set a time limit of 10 minutes (you may have to decrease this time limit if your classroom conditions are particularly cool). When the allotted time has elapsed, measure temperatures and compare volumes and colors of water.

Student strategies will vary. Some will increase surface area to air by pouring the water out into a tray and letting it stand. Others will pour cold water into the larger beaker and set the smaller beaker in it. Some may try running the hot water through the tubing and perhaps cooling the outside of the tubing with cool water. Others may just pour the water back and forth between the two beakers.

At the end of the time limit, have students pour water into original beakers and measure temperatures. Then inspect colors for evidence of dilution, and measure the volumes. Discuss their strategies. What worked best and why? (Answers will deal with heat transfer: water is a better heat transfer medium than air, so water cooling methods are generally more effective than *similar* air cooling methods.) What does this have to do with energy production and water use? (They may mention thermoelectric power plants. Many power plants use methods similar to theirs in cooling water.)

Now distribute Student Handout 19-1, "Thermoelectric Power Production and Water." You may use this handout as an individual assignment in class or as homework, or you may do it as a class, discussing as you go.

Answers to Student Handout 19-1

1. a. Approximately 200–500 times.
   b. Approximately 40 times.
   c. Approximately 4 times.
2. Water is used as a working fluid when it is changed to steam to turn turbines; it is used as a coolant in the condenser to condense the steam.
3. No. The working fluid is cycled through the system many times. In once-through cooling most of the withdrawn water is returned to the same source, with little evaporation before

it returns.

4. The experiment only investigated one aspect of the effects of thermal pollution, direct death, and that for an insufficient length of time. Some suggestions for improvement might include controlled experimentation on respiration, reproduction, competition, oxygen depletion, etc.
5. a. The summertime effects on the trout could be lethal.
   b. A temperature increase of 5°C or more probably resulted from the power plant's thermal discharge. Largemouth bass found the conditions more suitable to their growth, while northern pike found conditions less suitable for growth.
6. a. Dry tower: consumes the least amount of water.
   b. Dry tower: land not available for cooling ponds, weather conditions poor for evaporation, and wet cooling might cause dangerous fogs on the highways.
   c. Wet tower: land too expensive for cooling ponds; water not enough of a problem to warrant expense of dry tower.
   d. Cooling ponds: land isn't a problem, weather conditions are suited to evaporation.
7. If water supplies were limited, a coal-fired plant might be chosen over a nuclear plant because a coal plant requires about half the cooling water of a nuclear plant of the same capacity.
8. a. One-fifth to one-sixth. (Note: this does *not* mean that one-sixth of the nation's runoff is running through our power plants at one time. The same runoff can be used several times downstream.)
   b. One plant.
   c. Greater. It can cause corrosion of equipment, so materials used in design must be different. If cooling towers are used, they will need to be cleaned of salts left by evaporating waters. If cooling ponds are used, they need to be cleaned periodically.

Student Handout 19–1
Thermoelectric Power Production and Water

The laboratory activity that you just concluded demonstrated a variety of water cooling techniques. Water for cooling in thermoelectric power plants is the major withdrawal use for offstream energy production in the United States. Look at Figure 1, "Typical Water Requirements for Energy Production by Process and Type of Fuel." You can see that thermoelectric cooling dwarfs all the other uses of water in energy production.

In thermoelectric power plants, it is steam that turns the turbines to generate electricity. The steam is generally produced by heating water, either through combustion of a fossil fuel such as oil, coal, or natural gas, or from a controlled nuclear fission reaction.

In Figure 2, you see a diagram of a typical fossil fuel generating plant. The phases occur in this order:

1. The fuel is burned in the furnace.
2. It heats the water and vaporizes it to steam.
3. The steam turns the blades of a turbine; and the generator coils, moving in a magnetic field, produce electricity.
4. The steam is condensed to water by cooling.
5. The water returns to the boiler to go through the cycle again.

A nuclear power plant, diagramed in Figure 3, differs from a fossil fuel plant in the manner in which the steam is produced. In the nuclear facility, a controlled fission reaction produces the heat which is transferred to water (1). Then, in a heat exchanger, other water is heated by the reactor water and steam is produced (2). The rest of the system is very similar.

Water travels through both fossil and nuclear plants to produce steam to drive the turbines; but most of the water in these generating plants is used in the condenser. Cool water is continually brought in from the river, lake, or bay and circulated to condense the steam. A 40 percent efficient 1,000 megawatt (MW) fossil fuel plant requires 15,500 gallons/second. These tremendous amounts of water are not consumed; but returning this water to the source after it has absorbed heat from the power plant can cause thermal pollution. See page 122.

The easiest way to cool a power plant has been to pump the water from a lake, river, or bay, circulate it through the condenser, and return it to the source at an elevated temperature. This technique, called *once-through* cooling, can cause a rise of up to 30°F (17°C) in the temperature of the body of water immediately surrounding the plant, and elevated temperatures may be found as far as 40 km away. Such an increase can have serious impact on ecosystems. The effects can include:

- direct death of organisms due to heat,
- changes in respiration, growth, digestion, etc. of organisms,
- death through indirect effects of heat (reduced oxygen, decreased resistance to toxins, decreased availability of food supply),
- interference with reproduction or other critical life activities,
- replacement of one species by another more tolerant species.

It is clear that temperature plays a critical role in the aquatic environment. Increasing the temperature not only decreases the amount of dissolved oxygen the water can hold, but it also speeds up the metabolism of many organisms so that they require more oxygen. Experts agree that any large temperature change in an ecosystem will cause changes in the aquatic ecology of that ecosystem, and even small temperature changes often damage the delicate mechanism.

Figure 1
Typical Water Requirements for Energy Production By Type of Fuel and Process

Type of Fuel or Process	Water Requirements per million BTU (gal.)	Water Use
Western Coal Mining	0.25–0.61	dust control/washing
Surface Mine Reclamation*	0.38–3.0	watering vegetation
Eastern Coal Mining	0.66–0.75	dust control/washing
Coal Slurry Pipeline	10.1	transport fluid
Oil Production	3.05	drilling/recovery
Oil Refining	7.58	process and cooling
Shale Production	30.1	mining, cooling, processsing, waste disposal
Power Generation Fossil Fuel	120.16	cooling
Power Generation Nuclear	234.46	cooling

Sources: The Nation's Water Resources: The Second National Assessment, Part I, U.S. Water Resources Council, 1978, p.132.

Environmental Data for Energy Technology Policy Analysis, Vol.I: Summary, Mitre Corporation, Jan. 1979.

*data for one mine only, in Wyoming

Several techniques can be used to cool the water discharged from a thermoelectric plant. Four alternatives are outlined below and keyed to diagrams on page 123, "Cooling Alternatives for Power Plants."

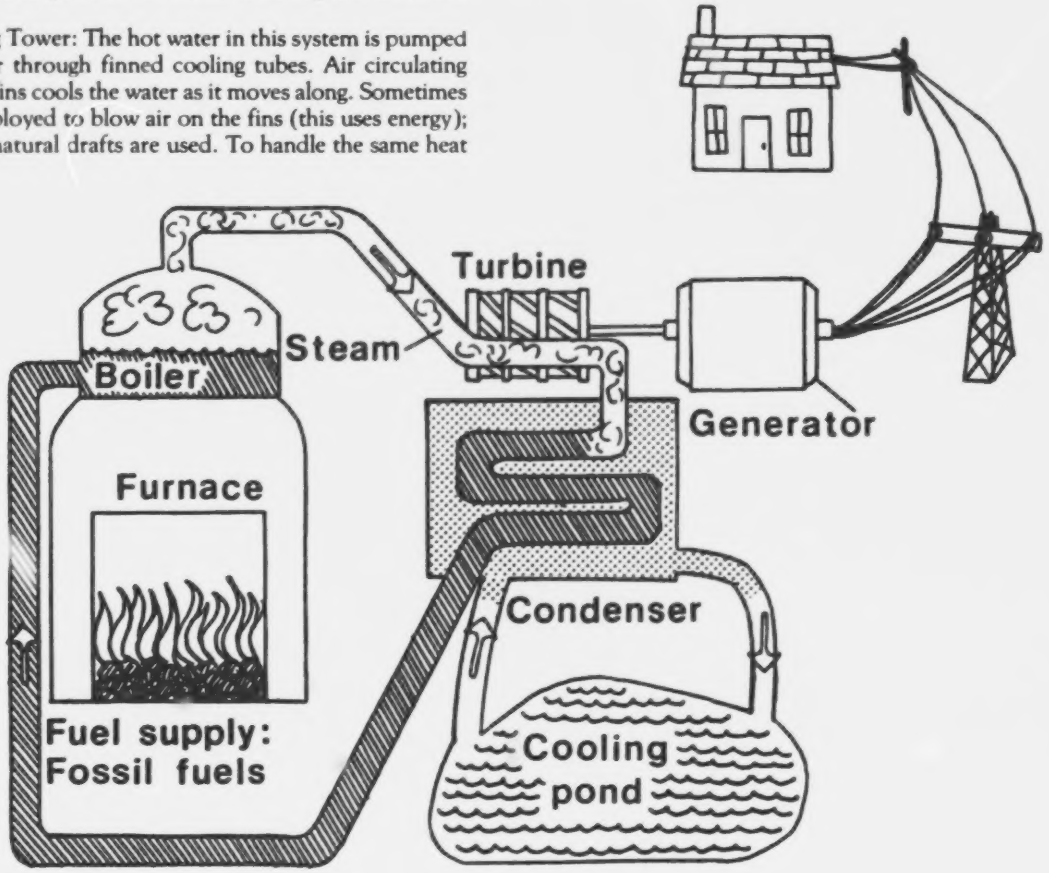
a. Once-Through Cooling: Water is pumped into the condenser at an upstream site and discharged directly into the same body of water downstream. This is the least expensive cooling method, but it results in extreme thermal pollution and elevation of temperature in an ecosystem.
b. Cooling Ponds: Hot water is discharged into a large pool where it is cooled mainly by evaporation. The cooled water is pumped back into the plant. A 1,000 MW plant requires 1,000–3,000 acres of cooling pond surface. The lower figure applies only in areas of rapid evaporation. In some cases,

sprayers are used to increase the rate of evaporation, and cooling pond size can be reduced. In systems that use cooling ponds, water must be continually supplied to replace that which is lost to the system through evaporation.

c. Wet Cooling Tower: Hot water is brought to the top of a tower and is sprayed or trickled down over a latticework. The heat is transferred to the air largely by evaporation. The cooled water is collected at the bottom and pumped back to the condenser. Replacement water required in this process is only 2–4 percent of what is needed in once-through cooling. The evaporation process can create local fog and increased humidity.

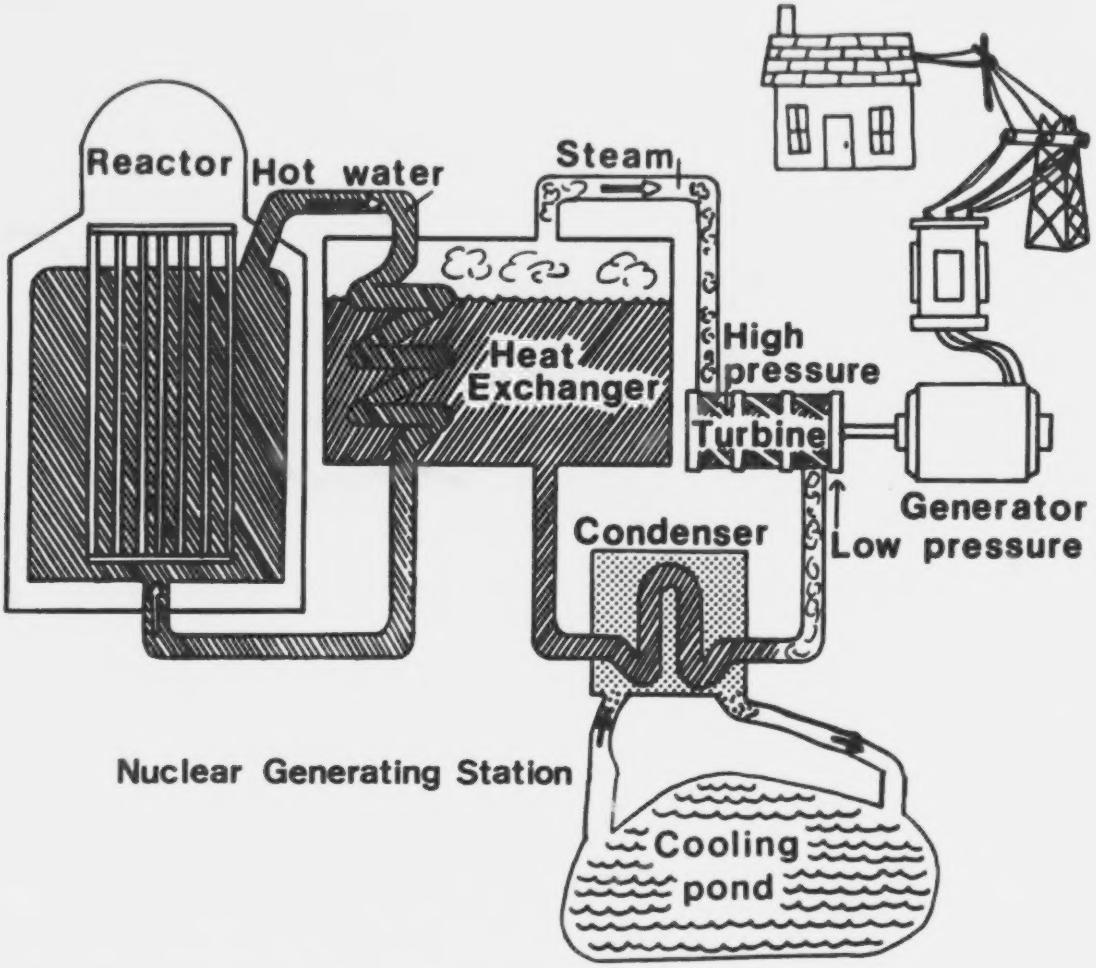
d. Dry Cooling Tower: The hot water in this system is pumped into a tower through finned cooling tubes. Air circulating around the fins cools the water as it moves along. Sometimes fans are employed to blow air on the fins (this uses energy); sometimes natural drafts are used. To handle the same heat load, dry cooling towers have to be much larger than wet towers, so they are more expensive to build. However, a major advantage of dry cooling towers is that they do not lose water to evaporation.

In conclusion, thermoelectric power plants withdraw large amounts of water which is used mostly for cooling. The simplest cooling process, once-through cooling, returns heated water directly to its source and causes thermal pollution. Fortunately, several alternative techniques can cool the water for reuse by the power plant.



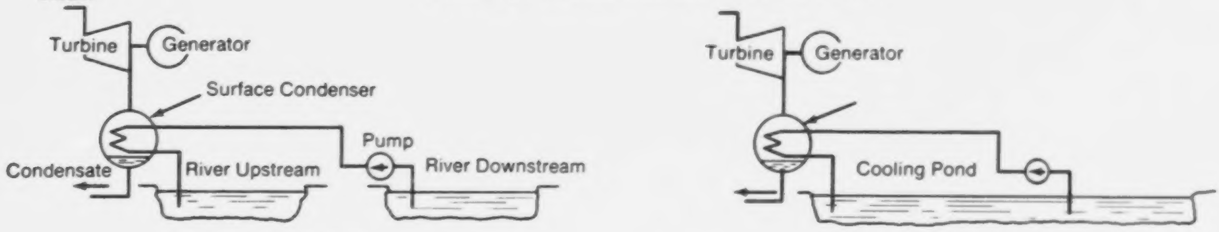
Use the readings and diagrams to answer these questions.

1. How many times more water is needed, per Btu of fuel produced, in cooling a fossil fuel plant than in:
   a. western coal mining?
   b. oil production?
   c. shale production?
2. There are two main uses of water in a thermoelectric plant—as a working fluid and as a coolant. Explain.
3. Do you think that much water is *consumed* by either of the above uses if once-through cooling is employed? Explain.
4. In attempting to argue that elevated temperatures did not affect a certain species of fish found in a bay near a thermoelectric plant, it was stated that caged fish kept in the warmed area near the plant for 2 weeks did not die and did not appear to have been adversely affected.
   Criticize this experiment and suggest ways to improve it.


Reactor
Hot water
Steam
Heat Exchanger
High pressure
Turbine
Generator
Low pressure
Condenser
Cooling pond

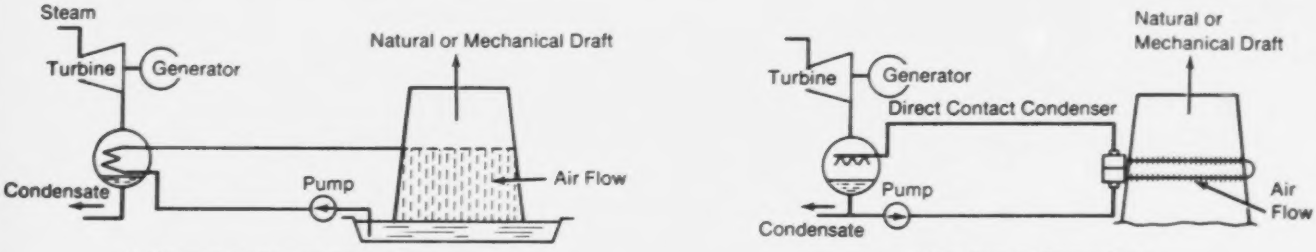
Nuclear Generating Station

Cooling Alternatives for Power Plants


Steam
Turbine
Generator
Surface Condenser
Pump
Condensate
River Upstream
River Downstream
Turbine
Generator
Cooling Pond

A. Once-through Cycle

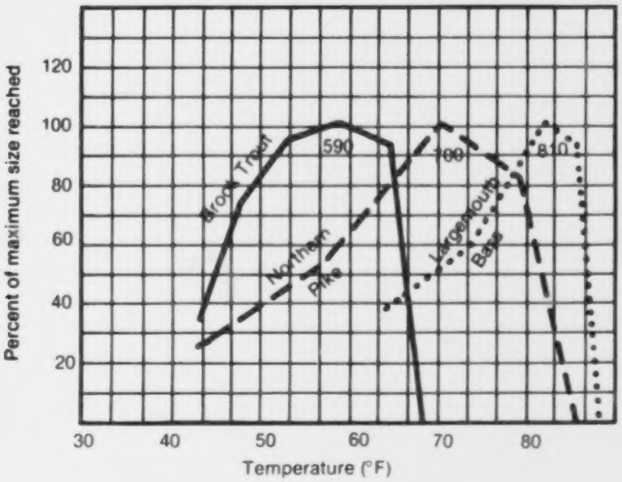
B. Cooling Pond Cycle


Steam
Turbine
Generator
Natural or Mechanical Draft
Air Flow
Pump
Condensate
Natural or Mechanical Draft
Turbine
Generator
Direct Contact Condenser
Air Flow
Pump
Condensate

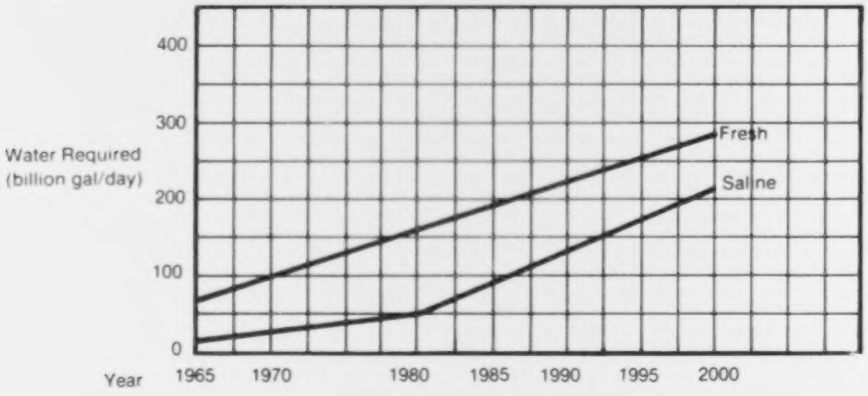
C. Evaporative Cooling Tower Cycle

D. Dry Cooling Tower Cycle

5. Look at the graph below and answer the following questions.



   a. A thermoelectric power plant is to be built on a river containing brook trout. The river averages 7°C in winter and 15°C in summer. What will be the effect of raising the temperature of the water –12°C within 25 miles downstream of the plant?
   b. A thermoelectric power plant is located on a large lake. The area near the plant was once noted for its fine northern pike fishing. Now the catch is predominantly largemouth bass. Explain.
6. For each of the following proposed sites of a thermoelectric plant, choose the best cooling technology (wet tower, dry tower, cooling pond) and defend your choice.
   a. Arid site, water available for consumption is low.
   b. Urban site near major highways, land is expensive and humidity is high.
   c. Rural site, most land is farmland and expensive, water for consumption is not a major problem.
   d. Rural site, land relatively inexpensive, generally low humidity and good natural breezes.
7. If a utility company is debating whether to build a coal or nuclear electric generating plant, how might water availability enter into this decision?
8. Look at the table below. It shows present and future projected water requirements for electric power plants.
   a. If annual runoff for the U.S. is 1,200 billion gallons, approximately what fraction of this will run through power plants in 1990?
   b. Flood conditions account for 2/3 of runoff in only 1/3 of the year. The Hudson River has a runoff of 310,000 gal/sec in flood stage, but only 15,500 gal/sec in dry periods. Return to your reading to determine how many 1,000 MW plants the Hudson could accomodate.
   c. A relatively large percent of cooling water for power plants is salt (saline) water. Is a greater or lesser proportion of the total expected to be from the ocean in the future? Can you think of any problems associated with using saltwater for cooling?



Present & future cooling water requirements for electric power plants